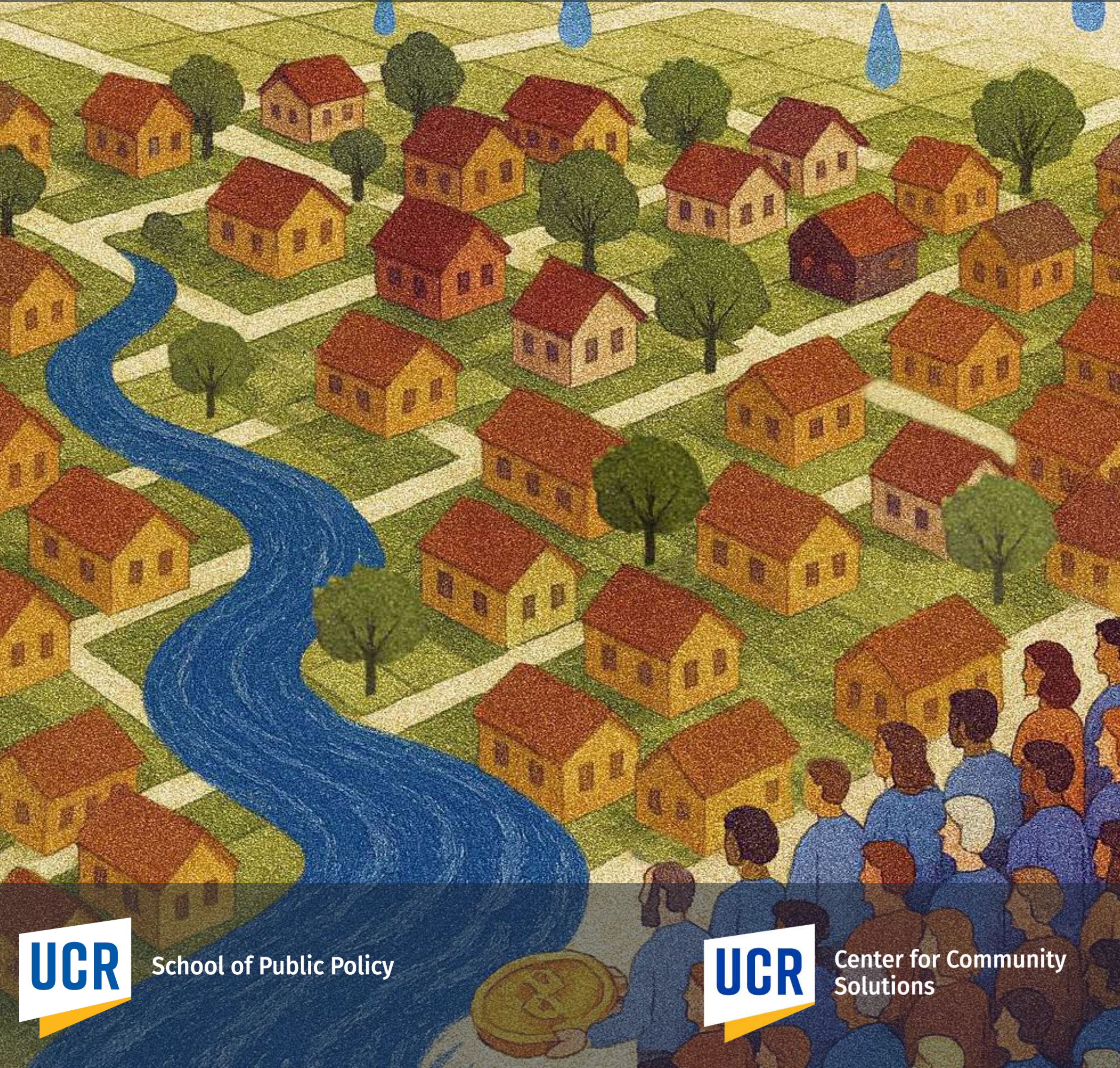
Affordability Impacts of Alternative Funding Schemes to Finance the Costs of Meeting MS4 Permit Regulations in the City of Riverside



UCR School of Public Policy

UCR Center for Community Solutions

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1 Executive Summary

This research aims to evaluate the impacts of various funding strategies on covering the estimated costs required to meet the requirements of the Clean Water Act's Municipal Separate Storm Sewer System (MS4) Permit regulations. Under this regulation, local governments are responsible for regulating and reducing the amount of pollution caused by stormwater runoff from public storm drainage systems, including roadways, gutters, and storm drains. To ensure that municipalities meet all the requirements, the Regional Water Quality Control Boards and the State Water Resources Control Board are responsible for enforcing these permits. According to these regulations, Phase I MS4 permits require extensive stormwater management plans to safeguard water quality in California cities with more than 100,000 residents [1] . For the City of Riverside, as part of California, current estimates indicate that it will need to generate approximately $10 million annually to meet the financial commitments for this permit.

The City of Riverside collaborated with the School of Public Policy and its Center for Community Solutions at the University of California, Riverside (UCR), to assess potential taxation methods to fund the expenses associated with this permit. The focus of this study is to evaluate and compare the affordability measures of alternative funding mechanisms (i.e., parcel-based and property-based) on different types of property ownership. A particular focus of the analysis is on the additional costs residential households confront under the different schemes. The particular measure we calculate is akin to an affordability ratio (i.e., the fraction of income that would be used to cover the additional expenditures a household would confront). Given that such additional expenditures may burden lower-income households, we use two income measures: median household income and 20th percentile income.

Regarding the parcel-based scheme, many municipalities use this method as a proxy to represent the relative contribution of each property to stormwater runoff. This tax scheme is based on land area that is represented by developed area or total impervious surface[1] coverage to distribute the costs proportionately [2]. This method is currently being used by the City of Riverside as part of its existing taxation plan, to be added to the utility bill. However, the current system and data can benefit from updates, especially in using recent parcel-level data on land use area.

Alternatively, the property tax scheme uses the value of each parcel to calculate the annual cost. This approach might be seen as assigning costs to parcels based on personal or corporate wealth, as reflected by property value.

Before presenting the overall findings from the analysis, it is useful to recognize how stormwater ran off.

1.1 Overall Findings

For parcel-level revenue-generation strategies that include land characteristics at the parcel-level, those that more accurately represent land factors across all land types, including residential land types, result in

[1] In this study, developed area refers only to the building footprint (rooftops), while impervious area includes all surfaces that do not absorb water such as rooftops, driveways, concrete, and pools. Therefore, developed area is a subset of impervious area.

lower median costs per parcel, on average. Designation of Beneficial Assessment Units (BAU) of "one" for single-family residential parcels but assigning BAU values based on specific runoff factors and parcel size for other land types results in greater area assumed to result in storm water runoff, especially from single-family residential households. Consequently, by treating single-family resident parcels similar to other land types (i.e., not assuming a BAU of one for each parcel), the costs to residential ratepayers are lower, on average, compared to approaches that ignore such differences and assume a BAU of one for all single-family residential parcels. The costs to residential ratepayers is lower, on average, compared to approaches that do not recognize such differences. These lower costs lead to less burden on households as measured by lower affordability ratios.

For parcel-based revenue generation schemes that define a broader array of parcel characteristics as runoff-enhancing (i.e., impervious) other than just buildings, the average costs per parcel contributing to runoff decreases. Strategies that include land surfaces such as concrete driveways, asphalt, and hard surfaces in their categorization of impervious surfaces, rather than simply a building footprint, result in more measured area as impervious and thus more area subject to the parcel tax thereby lowering the tax per BAU. Consequently, these lower costs lead to less burden on households as measured by lower affordability ratios.

The parcel-based method and the property-based method are very similar in their mean and median affordability values, but they differ in the shape of their distributions. The property-based method shows higher variation (SD) and the largest maximum values, while this method also gives more stable results across sub-methods. Under both MHI and 20th-percentile income metrics, the mean and median values are close, yet the parcel-based method still shows lower extremes overall. However, this method is also more sensitive to design choices, whereas the property-based scheme is more predictable, even when their typical (median/mean) burdens are similar.

Property-based revenue generation schemes that are adjusted by the faction of impervious surface relative to overall parcel size result in higher costs per unit area, only slightly though, relative to a straight property-tax related scheme. By weighting property values by their fraction of impervious surface relative to overall property area results in a lower level of total assessed value within the City of Riverside and thus a higher rate per parcel would need to be charged to recoup the annual $10 million cost. Higher costs per parcel lead to more burden on residential households as measured by the fraction of their income that would be needed to cover the costs, although again, only marginally so.

While the number of lower income households that exceed what are often commonly used threshold values for affordable water is 3 to 6 times greater than the number of households when measured assuming a median household income value, the percentage of households range from between 0.1 to 0.9% of the overall number of households in Riverside. Assuming an affordability threshold of 2.5% that is often used for drinking water expenditures at the household level, i.e., 2.5% of income going towards 6 CCFs of water that would represent a human right to water, the number of households that exceed this ratio at a 20% percentile ranges from 558 to 613 household out over 63,000 households depending tax scheme, the total number of households in Riverside is greater than 63,000.

In general, whether a parcel-level tax or property tax is more or less "affordable" to residents of Riverside is dependent on the characteristics of the specific scheme. That is, the level of costs and impacts on affordability are more so influenced by how impervious surface is defined and what sort of runoff factors single-family resident homes are assigned rather than if the city opts for parcel-level tax or a property-based tax.

Yet the fraction of income spent by residents in the City of Riverside to cover the costs of the program is generally less than 0.2% of their overall income. The most burdensome method to recover costs is the parcel-level tax that doesn't recognize differences across single-family residential households in terms of their contribution to runoff, although the affordability ratio is still less than 0.2%, on average. The property-tax based methods are slightly more expensive, assuming income represented by 20th percentile income, although the affordability ratios are still not above 0.2%, on average.

2 Introduction

This research aims to evaluate the impacts of various funding strategies on covering the estimated costs required to meet the requirements of the Clean Water Act's Municipal Separate Storm Sewer System (MS4)

Permit regulations[2]. Under this permit, local governments are responsible for regulating and reducing the amount of pollution caused by stormwater runoff from public storm drainage systems, including roadways, gutters, and storm drains. To ensure that municipalities meet all the requirements, the Regional Water Quality Control Boards and the State Water Resources Control Board are responsible for enforcing these permits. According to these regulations, Phase I MS4 permits require extensive stormwater management plans to safeguard water quality in California cities with more than 100,000 residents [1]. For the City of Riverside, as part of California, current estimates indicate that it will need to generate approximately $10 million annually to meet the financial commitments for this permit[3].

The City of Riverside collaborated with the School of Public Policy and its Center for Community Solutions at the University of California, Riverside (UCR), to assess potential taxation methods to fund the expenses associated with this permit. The focus of this study is to evaluate and compare the affordability measures of alternative funding mechanisms (i.e., parcel-based and property-based) on different types of property ownership. A particular focus of the analysis is on the additional costs residential households confront under the different schemes. The particular measure we calculate for comparison is akin to an affordability ratio (i.e., the fraction of income that would be used to cover the additional expenditures a household would confront). Given that such additional expenditures may burden lower-income households, we use two income measures: median household income and 20th percentile income.[4]

Regarding the parcel-based scheme, many municipalities use this method as a proxy to represent the relative contribution of each property to stormwater runoff.[5] This tax scheme is based on land area that is represented by developed area or total impervious surface[6] coverage to distribute the costs proportionately [2]. This method is currently being used by the City of Riverside as part of its existing taxation plan, to be added to the utility bill. However, the current system and data can benefit from updates, especially in using recent parcel-level data on land use area.

Alternatively, the property tax scheme uses the value of each parcel to calculate the annual cost. This approach might be seen as assigning costs to parcels based on personal or corporate wealth, as reflected by property value.

After developing estimates of the costs per property based on the two general schemes, the study examines the affordability of such schemes by evaluating the variation in household financial burden towards stormwater treatment under each. To achieve this, spatial data such as parcel-level land use and socioeconomic variables from the U.S. Census Bureau were used. Furthermore, to account for the effects on middle-class families and those in the lowest income bracket, affordability is measured using both the Median Household Income (MHI) and the 20th percentile income.

This report details our research methods and findings. The results provide the City of Riverside with information on the costs and affordability of different stormwater finance mechanisms for its stakeholders.

2.1 Literature review

Stormwater refers to runoff from rain that flows over impervious surfaces, potentially carrying pollutants into natural waterways [3]. In 1987, the United States legislature included stormwater regulation in the Clean Water Act amendments, which gave the Environmental Protection Agency (EPA) authority to require the National Pollutant Discharge Elimination System (NPDES) permit. As a result, stormwater discharge

[2] See here for more information: https://riversideca.gov/publicworks/other-services/stormwater

[3] This decision was based on the conversations with City of Riverside Flood Control District and authors in June 2025.

[4] While median household income (MHI) captures that level of income for which 50% of the population is above and below, 20th percentile income is that level for which only 20% of the population is below (and 80% above). It is a widely used measure to represent lower income households within a geographic area.

[5] A challenge with this approach is that since it does not account for actual rainfall-runoff contributions from each property to measured stormwater flows, which would likely require significant transactions to implement (for monitoring and measurement), it is thus an imperfect proxy

[6] In this study, developed area refers only to the building footprint (rooftops), while impervious area includes all surfaces that do not absorb water such as rooftops, driveways, concrete, and pools. Therefore, developed area is a subset of impervious area.

permits have been implemented as part of the MS4 Phase I and II projects, which applied to both big and small cities, respectively. Although permits initially allowed for greater flexibility in terms of compliance, EPA is currently pushing for more stringent regulations by implementing numerical restrictions, particularly in cases where discharges impact damaged water sources. Consequently, cities may face a substantial increase in infrastructure and compliance expenditures due to these changes [4, 5].

To cover similar costs around the world, governments have implemented various methods for distributing the costs of stormwater management, including flat-rate charges, impervious-area-based fees, property-value-based assessments, water-usage-based rates, hybrid approaches etc. These methods usually aim to ensure the financial sustainability of urban stormwater systems while considering environmental and social objectives [5]. However, in the USA, stormwater funding is commonly based on flat rates, impervious surface area, or hybrid models combining both approaches. These mechanisms have proven to be effective and equitable, while allowing local governments to cover costs without an excessive pressure on general public budgets [4].

Even though the United States as a whole views stormwater finance systems as beneficial, different cities, even within the same state, have had different experiences [6]. For instance, a study of 80 Washington jurisdictions shows a variation in stormwater rate structures (flat, impervious-area-based, hybrid) resulting in yearly rates ranging from $42 to more than $1,000. Moreover, in spite of more stringent rules, several Phase II communities have failed to increase fees, putting them in danger of being underfunded. Their report emphasizes the need for improved rate-setting, political support, and help programs (e.g. providing financial assistance programs for low-income households), and also refers to equity difficulties, particularly with flat rates impacting low-income households [6].

Among various methods used in the U.S., several studies suggest combining a flat rate with impervious area measurements as an effective approach. For example, Lee et al. [7] discussed the advantages of a dual-method approach based on impervious surface area, highlighting its potential to address the inefficiencies and inequities associated with a fixed-rate stormwater fee in Corpus Christi, Texas. Their analysis emphasized how the existing flat-rate system disproportionately burdens low-income and Hispanic households (using MHI for affordability analysis), while wealthier families, despite owning larger parcels that contribute more to stormwater runoff, end up paying relatively lower fees. Similarly, Porse et al. [8] use the Equivalent Residential Units (ERU) unit for assessing the stormwater fee for each parcel in Sacramento County, California. This method assumes a flat rate for residential land uses, considering just impervious areas as the effective area for the tax policy, and finally assessed the tax affordability by MHI. By this assessment, they realized that this method reduces the burden on low-income families with annual fee below the affordability threshold for most families. They concluded that this method not only could benefit the environment but also has better performance in terms of social financial equity.

Finally, while a stormwater utility fee is increasingly being used across U.S. cities, there is a lack of evidence on how different methods affect public behavior, equity across income groups, and long-term revenue sustainability [9]. In this research we aim to discuss more about these gaps, particularly through an affordability lens. Consequently, this study contributes to the literature by evaluating the affordability implications of different stormwater funding methods, using detailed parcel-level data from the City of Riverside, California.

3 Data

3.1 Data Sources

To compare alternative revenue-generation schemes, the study required detailed spatial and socioeconomic data that could be linked to each parcel in the City of Riverside. The spatial databases enabled the determination of critical variables for calculating parcels' annual taxes under various billing schemes, including impervious surface coverage, land area, and built area, at the parcel level. The following geospatial data were used in this research.

3.1.1 City of Riverside Boundary Shapefile

The City of Riverside boundary shapefile [10] defines the official limits of the City of Riverside. This layer was used to spatially filter all layers to the relevant analysis area and exclude any irrelevant data from various sources. This layer was updated by the City in

June 2025 and provided as part of the publicly available open-source data by the City of Riverside.

3.1.2 Parcel Boundary and Land Use

A parcel-level layer was also provided through open-source data updated in April 2023 [11]. This data set consists of a variety of variables, including parcel boundaries, land use classifications, and ownership types. It was used to assign tax factors (refer to Table 1) and to calculate parcel area.

3.1.3 Building Footprints

This dataset consists of building footprints that were prepared by Esri for potential integration with OpenStreetMap. The footprints were originally created by the City of Riverside (last updated in 2021) [12]. Moreover, this publicly available dataset provides the foundation for estimating the developed area per parcel measures.

3.1.4 Impervious Area

The County of Riverside provides this data, and it is publicly available upon request. It was collected by NearMap[7] in 2023 using AI-based surface classification tools. The impervious surfaces included in this dataset are asphalt, concrete slabs, building footprints, hard surfaces, and pools.

3.1.5 Property value

A crucial aspect of this research relies on assessed land values derived from the Open Data Hub in Riverside County [13]. This hub provides access to public updated parcel-level information. The County Assessor's Office updates the parcel attributes, and this platform delivers a monthly extract of them. Parcel ID, land use code, ownership type, area, and several value indicators are some of the variables included in this dataset.

For this research, data from September 2025 is used. In this dataset, the sum of "LAND" and "STRUCTURES" variables represents the assessed land value of each parcel. Stormwater costs per parcel are based on this Land variable that is assigned to each parcel layer (see 3.1.2) by APN number.

3.1.6 Block Group for Census Data Sources

We use the US Census block group boundaries, commonly referred to as TIGER/Line (2024) [14], to spatially join our income data tables with parcel maps and calculate the affordability metrics. Note that income (and any other socioeconomic data, if applicable) is not available at the parcel level. The common practice in water affordability analysis is to use median household income at the most granular level available (i.e., census block groups) to measure affordability impacts [15].

3.2 Socioeconomic Data Sources

To further understand how financial pressures could differ by income bracket, income statistics were also included. The following census data were used in this research as socioeconomic data sources:

3.2.1 Median Household Income (MHI)

According to the American Community Survey (ACS), Median Household Income (MHI) refers to the median pretax cash income of all household members aged 15 and older. MHI includes households with no income and represents the midpoint that divides all households into two equal halves [16]. In this study, parcel-level affordability ratios were calculated using MHI data obtained from the ACS 5-Year Estimates at the block group level for the City of Riverside [17].

3.2.2 The 20th Percentile Income

To better represent water affordability challenges for lower-income households, the 20th percentile income is used to calculate the Affordability Ratio in addition to MHI.[8] The 20th percentile income captures the bottom end of the income distribution. To calculate this estimate, we used the number of households in each income bracket, divided by block group (see Section 3.1.6), from the 5-Year ACS Estimates [19]. This metric enables us to assess the impact on the affordability of lower-income households, providing a more conservative measure of income than MHI.

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[7] https://www.nearmap.com/

[8] Using the 20th percentile, or lowest quintile, income has become a common approach to represent income for lower income households [18]. A unique element to the approach taken here to estimate the 20th percentile income is to weight each income-category by its respective population (midpoint of population range) for each census block group.

4 Methodology

This study examines two main types of revenue-generation schemes, including a parcel-based tax (Method 1) and a property value-based tax (Method 2), to calculate annual tax for each parcel and explore how different funding mechanisms affect affordability and equity. The main difference between how stormwater fees are distributed across properties under these two schemes is that the former (i.e., parcel-based tax) is based on the physical attributes of the parcel, while the latter method relies on assessed market value. We also analyzed multiple scenarios under each method by changing variables such as the use of developed versus impervious land as the basis for cost allocation. These additional permutations provide a deeper understanding of how particular assumptions within each method influence outcomes.

4.1 Parcel-based Tax Scheme (Method 1)

The parcel-based taxation scheme is based on the County of Riverside's CSA 152 NPDES Program Assessment model [20, 21]. This method calculates stormwater fees based on a parcel's expected contribution to runoff. The main concept is to charge a fee directly related to a property's area and land use category. Under this approach, a unit called the Benefit Assessment Unit (BAU) is used to standardize the evaluation of runoff potential across different parcel types and land uses.

To ensure consistency in parcel classification, the CSA 152 NPDES program defines six land use group categories. These categories reflect the various types of development and the anticipated contributions of stormwater runoff. While different sub-methods employ various techniques to calculate BAUs, Table 1 presents the different land use categories considered under the program.

Table 1- BAU Groups [21]

Group	Land uses	Per Acre (rate)
A	Commercial and Industrial properties	12
B	Multi-Family Housing, Mobile Home Parks, Churches, and Schools	9
C	Single-Family Residential parcels	6
D	Agricultural and Vacant parcels	0
E	Golf Courses and Private Parks	0.10
F	Miscellaneous parcels with minor structures	0.05

In this table, "per acre" refers to the rate assigned to each acre (43,560 square feet) of developed land within a parcel. Using this rate, parcels that are subject to more intensive use, such as commercial or industrial developments, typically have higher rates since they generate more runoff per acre, ceteris paribus. In fact, this rate is significantly important to the cost allocation process, since it determines the number of BAUs attributed to each parcel. Based on this method, the number of BAU per parcel is calculated as:

BAU=Parcel Area (in acres) × (Per Acre rate)

After the BAUs are allocated to each parcel according to the logic specific to each sub-method, the annual stormwater fee is calculated using a uniform cost distribution formula. The rate per BAU in USD is determined by dividing the City's total revenue requirement (in this study, $10 million annually) by the total number of BAUs across all taxable parcels:

(1) $\text{Total revenue} = \$\ \text{rate per BAU} \times \text{Total BAUs}$

(2) $\$\ \text{rate per BAU} = \frac{\$\ 10\ million}{Total\ BAUs}$

(3) $\text{Annual fee per parcel} = \$\ \text{rate per BAU} \times \text{parcel BAU}$

To calculate parcels' BAU, the following sub-methods are used as parcel-based scheme methods:

4.1.1 Method 1.1 parcel-based tax scheme, based on developed area, with flat BAU for Group C

For this method, we follow Riverside County's current CSA 152 NPDES Program Assessment [20, 21] framework directly. We assume a flat-rate approach for single-family residential parcels (i.e., Group C, Table 1), so that area is not a factor for these parcels but employ an area-based calculations for all other land use categories. The core idea is to simplify billing for the largest group of parcels, which are single-family residences, and also to maintain a balance for different land uses with considerable runoff, such as commercial or multi-family projects. The BAU for this Method is calculated as:

For Group C (Single-Family Residential) parcels:

(4) *BAU= 1 (Flat)*

For Groups A, B, D, E, F parcels:

(5) *BAU = Developed Area (in acres) × (Per Acre rate)*

Developed area in this equation refers to building footprints in each parcel or land (see 3.1.3), and the per-acre rate is provided in Table 1.

4.1.2 Method 1.2 parcel-based tax scheme, based on developed area, with effective BAU for all Groups

In this sub-method, the area-based technique used in Method 1.1 is uniformly applied to all land use groups, including Group C. This technique determines BAUs for each parcel by calculating the actual developed area and the appropriate per-acre runoff rate from Table 1. The sub-method's objective is to recognize the areas associated with all land uses, regardless of parcel type.

For all parcels Groups:

(6) *BAU = Developed Area (in acres) × (Per Acre rate)*

4.1.3 Method 1.3 parcel-based tax scheme, based on impervious area, with flat BAU for Group C

This sub-method adjusts the CSA 152 framework to ensure that BAU is estimated by impervious area (see 3.1.4) rather than developed area. This method provides a more realistic hydrological representation of potential parcel contributions, given that impervious surfaces are more directly associated with stormwater runoff.

In this sub-method, similar to Method 1.1, for Group C (single-family residential parcels), the BAU is set at a flat rate of 1. However, for all other land use groups, the BAU is determined by multiplying the impervious area by the relevant per-acre runoff rates from Table 1.

For Group C (Single-Family Residential) parcels:

(7) *BAU= 1 (Flat)*

For Groups A, B, D, E, F parcels:

(8) *BAU = Impervious Area (in acres) × (Per Acre rate)*

4.1.4 Method 1.4 parcel-based tax scheme, based on impervious area, with effective BAU for all Groups

For the last sub-method of the parcel-based scheme, impervious area is used as the basis for BAU calculations. Moreover, unlike Method 1.3, which assigns a flat BAU to Group C, this approach applies the same runoff-based formula to all parcels to ensure consistency and proportionality.

For all parcel Groups:

(9) *BAU = Impervious Area (in acres) × (Per Acre rate)*

4.2 Method 2 - Property-based tax scheme

In this method, stormwater fees are determined using the assessed market value of the property (see 3.1.5), rather than the physical characteristics used in Method 1. The basic idea behind this approach is that a property's market value can reflect a household's financial capacity to pay. As a result, this variable offers a simpler and more administratively efficient strategy, especially when the necessary data is publicly available. Considering total revenue equal to $10 million, in this method, the annual fee per parcel is calculated as follows:

(10) *Total revenue = $ rate × Property total Value*

Where Property total Value shows the sum of all taxable parcels' assessed land value in the city. Consequently:

(11) $$\$\ rate = \frac{\$\ 10\ million}{Property\ total\ Value}$$

(12) *Annual fee per property= $rate × Property Value*

Notably, as requested by the City of Riverside, for this method, we assumed that residential and commercial properties have equal cost shares (i.e., the same $ rate). This decision was made because distinguishing between these groups would require additional legal frameworks and complex economic modeling, which were beyond the scope of this research.

Another important point to note here is that churches and schools were excluded from this taxation scheme. These institutions are typically exempt from property-related fees due to legal and policy precedents. However, they can still participate voluntarily yet are not financially obligated.

Moreover, another change here was the exclusion of government-owned and nonprofit properties from the list of taxpayers. We applied this exemption because the California Constitution clearly states that properties owned by local governments are not taxable (Article XIII, Section 3b) [22]. In contrast, for Method 1, since we followed the City of Riverside's handbook for the current taxation approach, we chose not to make any modifications, as that method did not include any exemption for government and nonprofit properties.

To apply these exemptions, we used the ownership and land use variables from Data 3.1.2 and filtered out:

1) Any parcels whose owner names contained specific keywords indicating public or institutional ownership. These keywords included: "CITY," "COUNTY," "STATE," "UNIV," "UNIVERSITY," "COLLEGE," "DISTRICT," "SCHOOL," "AGENCY," "PUBLIC," "FLOOD," "TRANSIT," "WATER," "LIBRARY," "REDEVELOPMENT," "DEPT," "CHURCH," "CATHOLIC," "BAPTIST," "EPISCOPAL," and "HOUSING AUTHORITY", "SYNAGOGUE", "TEMPLE",

2) As well as any land uses under the following categories: "CHURCHES AND TEMPLES", "SCHOOLS", "CEMETERY", "PUBLIC FACILITIES", "PARKS".

After applying for this exemption, we excluded a total of 2,324 parcels[9].

For this method, similar to Method 1, several sub-methods were considered.

4.2.1 Method 2.1 property-based tax scheme, based on total land value

Under this approach, each parcel's stormwater charge is determined by its entire assessed land value. Regardless of the size or surface features, all taxable parcels (excluding churches, schools, and governmental properties) are included in the calculation.

For this method, properties with higher assessed land values are required to cover a larger proportion of total costs.

For all parcels that aren't excluded:

$$\text{(13)} \qquad \$\,rate = \frac{\$\,10\ million}{Total\ city\ taxable\ land\ value}$$

$$\text{(14)} \qquad Annual\ fee\ per\ property = \$rate \times Property\ land\ Value$$

4.2.2 Method 2.2 Property-based tax scheme, based on impervious land value

As an alternative to the overall property-based methodology, this sub-method analyzes the assessed land value of each parcel's impervious area. In other words, the assessment is not determined by considering the entire property value alone, but instead by assessing the value of the impervious land that is the primary source of runoff (including structures, roads, and pavement, see 3.1.4).

To estimate the annual fee per property under this strategy, it was first necessary to determine the price per square meter of property and then multiply that value by the impervious area of the property. After we get the value of the impervious land per parcel, we can substitute it into the equation for the annual charge. The formulas are:

$$\text{(15)} \qquad Price\ per\ m^2\ of\ land\ (\$) = \frac{Total\ land\ value\ (\$)}{Total\ land\ area\ (m^2)}$$

$$\text{(16)} \qquad Impervious\ land\ value = Impervious\ area\ (m^2) \times Price\ per\ m^2\ of\ land\ (\$)$$

$$\text{(17)} \qquad \$\,rate = \frac{\$\,10\ million}{Total\ city\ taxable\ impervious\ land\ value}$$

[9] Given the variation in names and representation, some nonprofit or tax-exempt parcels may not have been fully identified in this analysis.

(18) *Annual fee per property= \$rate ×impervious land Value*

4.3 Affordability Assessment

The affordability analysis is conducted after calculating the annual fee for each parcel using all the recommended sub-methods. For this research, the parcel-level annual fee in GIS was exported to R software for calculating affordability ratios, where block group-level income data was linked to each parcel. The affordability ratio has been calculated by dividing the annual stormwater fees for each parcel by both the MHI and the 20th percentile income at the block group level. These indicators were utilized to measure the average and lower-income household burdens, as mentioned before in Sections 3.2.1 and 3.2.2. Notably, all ratios were presented as percentages of income. Moreover, for each scheme, heat maps and statistical analyses of affordability were created using both income criteria to show how the financial burden was distributed across the city. These maps and analyses are presented in the results section.

(19) $$\text{Affordability Ratio-MHI} = \frac{parcel's\ Annual\ fee}{MHI - Parcel's block\ group} \times 100$$

(20) $$\text{Affordability Ratio-}20^{th}\text{-Inc} = \frac{parcel's\ Annual\ fee}{20th\ Inc - Parcel's block\ group} \times 100$$

5 Results and Discussion

This section presents the results of the various revenue collection strategies. All strategies were designed to generate \$10 million in annual revenue. After applying the respective formulas introduced in Section 2, we calculated the resulting annual stormwater fee for each taxable parcel across the City of Riverside.

5.1 Annual Fee Assessment

Summary statistics of our analysis for all six sub-methods' annual fees are summarized in Table A1.1(see appendices1).

Table A1.1 demonstrates that the rate per BAU differs considerably between sub-methods, and one of the main reasons for this is how BAU is calculated across sub-methods. In Method 1.1, assigning a flat BAU to single-family land uses results in a fee of \$124.82 per BAU. On the other hand, Method 1.2 is calculated based on the developed area for each parcel for all parcel types. This decreases the total number of BAUs and increases the rate per BAU to \$234.53 for Method 1.2.[10] The change in number of BAUs in 1.2 also introduces more variability, reflected in a higher *IQR (33.53 vs. 0) and standard deviation (718.74 vs. 376.62) compared to 1.1.[11]

While moving from developed to impervious area, Methods 1.3 and 1.4 also reveal similar changes due to differences in BAU calculation. Method 1.3 shows a reduction in the BAU rate to \$66.87 by applying a flat BAU for single-family lots. The charge is slightly higher (\$74.10) for Method 1.4, which uses effective BAU and impervious area for all parcels. An increase in the standard deviation and the rise in the IQR from 0 to 64.06 indicate that the variability grows between 1.3 and 1.4, as well as between the first two methods, which isn't surprising since 1.1 and 1.3 both constrain the residential BAU to one.

Another reason for changes between Methods 1.1/1.2 and 1.3/1.4 is the area of assessment used for calculating BAUs. The former (1.1/1.2) is based on developed areas, which include building footprints, while the latter (1.3/1.4) uses total impervious areas, which is usually larger since it includes hard surfaces like roads and sidewalks. In terms of rates per BAU, Methods 1.3 (\$66.87) and 1.4 (\$74.10) result in higher total BAUs and, consequently, a reduced rate per BAU when compared to Methods 1.1 (\$124.82) and 1.2 (\$234.52). As seen in the IQR and standard deviation values, the use of impervious areas also causes more variability in parcel-level costs.

The main distinction in property-based approaches is the area whose value is used for the calculation. Method 2.2 the total property value by share of impervious area alone, while Method 2.1 uses the total land value of each parcel, which is much larger than in the former

[10] For residential properties, 1.1 assumes a BAU of 1. Consequently, the outcome that 1.2 has fewer BAUs is an outcome from the relationship between the area of development per parcel and the BAU *per acre rate*, the product of which for residential properties is less than 1, on average, for Riverside. This needn't be the case for other jurisdictions.

[11] IQR is the Inter-quartile Range and captures the distance between the first quartile and the 3rd quartile. The greater the IQR the greater the degree of dispersion or variability.

method. This change causes Method 2.2 to have a higher $ rate ($00.000389) than Method 2.1 ($0.000238), which in turn increases both the mean charge ($166.73 vs. $138.64) and the median cost ($86.16 vs. $81.76). Moreover, in Method 2.2, the greater standard deviation (953.27 vs. 649.97) and IQR (93.43 vs. 79.38) suggests broader variation among values, with slightly higher skewness (55.31vs. 44.99).

To provide a visual illustration to Table A1.1, this research also includes Heat maps for all six sub-methods (see Appendices 1, Maps A1.1-A1.6).

5.2 Affordability Assessment

The affordability analysis examines the relationship between household income and the annual parcel-level fees identified in the previous section. To better reflect low-income households, in addition to representing household-level income by MHI, we also represent affordability by assuming a 20th percentile income level. Affordability ratio summary data for all six sub-methods are shown in Table A1.2 (see Appendices 1.

One of the first notable outcomes in Table A1.2 is that, as expected, the affordability ratios are higher when its calculated using the 20th percentile ratios rather than MHI, often by a factor of three or more. For example, in Method 1.1, the mean affordability is 0.16% of MHI compared to 0.45% of 20th income. A similar pattern is observed across all methods. Median values follow the same trend, for instance, in Method 1.2, the median burden rises from 0.07% (MHI) to 0.15% (20th), and in Method 1.4 it increases from 0.042% to 0.083%. In all cases, the median is lower than the mean, suggesting a right-skewed distribution with the presence of high outliers, also reflected in the maximum ratios, which range from 62.7% to over 743% of income.

Among the four parcel-based methods, Method 1.4 results in the lowest affordability burdens in terms of both median and mean, particularly under the MHI metric (0.04% median, 0.17% mean). This is expected since the median $ rate per BAU under Method 1.4 is the lowest as well. And while the maximum and standard deviation values are high, the very low Q1 and median values indicate that a large number of parcels fall well below affordability thresholds. Method 1.3 shows a similar pattern, though slightly higher in median and IQR (difference between Q3 and Q1). In contrast, Method 1.1 has the highest median ratio under both MHI and 20th metrics, suggesting that assigning flat BAUs to single-family parcels without accounting for size may lead to a greater financial burden relative to the other parcel-level methods.

Comparing Methods 1.1 and 1.2 to 1.3 and 1.4 reveals a clear downward shift in affordability ratios for the majority of parcels. Under the 20th percentile metric, median values drop from 0.20% (1.1) and 0.15% (1.2) to 0.11% (1.3) and 0.08% (1.4). A similar trend appears for MHI as the median falls from 0.12% and 0.07% to 0.06% and 0.04%. These reductions are also seen in Q1 values, reaching zero in Method 1.4 under both income metrics. Although the mean ratios change slightly across methods (0.16%–0.17% for MHI), the drop in typical burden suggests a more favorable outcome for the majority of households under 1.3 and 1.4.

Affordability results for Method 2 show lower burdens overall compared to parcel-based methods. Method 2.1 has the lowest mean ratio in the entire study (0.37% for 20th percentile income and 0.13% for MHI) while the mean value is slightly higher for the Method 2.2 (0.50% for 20th percentile and 0.15% for MHI). Comparing Method 2.1 and 2.2, median values are similar for both methods and under both MHI and 20th percentile assessment (0.01% and 0.03%, respectively with the lowest rate compared to Method 1).

To support deeper interpretation and geographical comparisons, affordability heat maps are also provided for all six sub-methods (see Maps A1.7– A1.18 in the Appendices 1).

5.3 Residential Parcel Counts Above Affordability Thresholds

To better understand the distributional impacts of each sub-method, we also examined the number of parcels whose stormwater fees exceed a certain portion of household income. Specifically, we report parcel counts where the affordability ratio exceeds 2.5% and 10% of income (see Table A1.2 in the Appendices 1). These metrics provide insight into extreme burden scenarios.

It is important to note that the total “Count” values in the table include all land uses, such as commercial, industrial, and vacant parcels. However, the affordability concept is only meaningful for residential land uses, as stormwater fees are compared to household income. Therefore, in our analysis, we will discuss only residential parcels to evaluate affordability more accurately (Count Group B and Count Group C in Table A1.2)

For parcel-based methods (Method 1), we relied on the CSA 152 land use classification system (see Table 1). We used Group B (including multi-family housing, mobile home parks, churches, and schools) and Group C (single-family housing) to identify residential parcels. In total, Method 1 includes 63,488 residential parcels across these two groups. On the other hand, for property-based methods (Method 2), residential parcels were directly identified using the *LanduseD* variable from the city's GIS parcel layer (see Section 3.1.2). This allowed us to more precisely isolate single- and multi-family properties and exclude irrelevant land uses. Method 2 includes 63,149 residential parcels.

Based on Table A1.2, there are obviously more households exceeding the 2.5% standard than the 10% standard, and more households that exceed either standard when a 20th percentile income measure is used relative to the MHI. Under the more stringent 2.5% threshold, no more than 0.6% of the households are above the threshold regardless of method. Method 1.4, which has the lowest median affordability ratio, results in the highest number of residential properties exceeding the threshold (407 under the 20th percentile income and 216 under MHI). Most of the residential properties arise from Group B classification, which includes multi-family residential household, and not the Group C classification, which is the single-family residential properties. Method 1.1 generally results in the fewest residential properties that exceed the threshold in Method 1.

In the property-based schemes, compared to Method 1, we have a lower number of properties that exceed 2.5% threshold. Again, it is clear the impact of using 20th percentile income relative to an MHI has on the number of properties that are above the thresholds, a nearly 2- to 6- fold increase. Yet, regardless of method, the percentage of households that exceed the thresholds, and similar to the parcel-tax method, is low. In Method 2, when using MHI, the percentage of households that exceed the 2.5% threshold is around 0.1%, while under a 20th percentile income level we see that the percentage increases to around 0.9%.

It is notable that although all methods keep the majority of parcels below affordability thresholds, the distinction between a few families being affected versus several hundred underscores the impacts of different approaches.

Figure A1.1 provides additional information by illustrating the full distribution of affordability ratios (using 20% percentile of the income) across all methods. The left panel shows that, for all land-use types, the majority of parcels lie well below the 2.5% threshold, with only a small number of extreme outliers. The right panel focuses on residential parcels (Groups B and C) and similarly shows that affordability ratios remain concentrated near zero for most households. However, there is greater variation among single-family parcels (Group B, blue) under method 1, while method 2 exhibits relatively tighter distributions across both land use groups.

5.4 Group-Based Share of Total Stormwater Fees

Figure A1.2 in the Appendices 1 shows the results of our analysis of the financial contribution to stormwater expenses distributed across different land use categories (Table 1).

For the parcel-based methods, Group C typically bears the largest share (from 71.9% in Method 1.1 down to 31.9% in Method 1.4), with the exception of Method 1.3 where group A, Commercial and Industrial Properties, bears a larger fraction of overall costs. As shown, as the methods move from simple area-based allocation (1.1) to impervious-surface-based approaches (1.4), the relative contribution of Group A increases sharply from 18.2% in 1.1 to 49.1% in 1.4. This is likely the result of residential property BAUs decreasing, on average, as the impervious land area and their land classifications are recognized (and not constrained to be "1").

In the property-based methods, the pattern is similar but less dramatic. Group C pays 51.92% in Method 2.1 and 42.87% in Method 2.2, while Group A rises from 19.87% to 27% as we move from total land value to impervious land value. Notably, in Method 1, as the per-acre rate (see Table 1) was zero for agricultural and vacant parcels (Group D), these parcels did not participate in tax payment. However, in Method 2, these parcels contribute based on land values and hold a significant share of about 19%, which helps reduce the burden on single-family housing or Group C.

All techniques show that Groups E and F contribute less than 1%, indicating that based on the used Method, Groups A, B, C and D, which mostly consist of business and residential buildings that bear the brunt of the financial burden, as well as vacant and agricultural land uses that contribute significantly in stormwater taxation schemes only under method 2.

5.5 Long-term Considerations Discussion

This section focuses on how key design features may shape long-term financial, environmental, and political outcomes. To better understand the broader effects of each sub-method, we categorize them based on these core design features.

A) Flat BAU for Residential Parcels (Methods 1.1 and 1.3):

The primary goal of using a flat BAU for single-family properties is to make the process easier and more transparent. This is especially important for Group C, which is the largest city's land use category in Table 1. However, this method may remove some important details from the process, particularly in more vulnerable or smaller areas. Over time, the gap between financial contribution, parcel size, and runoff potential could lead to perceptions of inequality. While the short-term impact may be limited to administrative work, the long-term effect might be reduced public trust and lower support for program expansion or modification. Moreover, since the system does not consider green or pervious areas, residents may continue developing all available land, which can increase the city's stormwater burden.

B) Effective BAU for all land uses (Methods 1.2 and 1.4):

This approach uses the actual developed area to calculate BAU for all parcel types, including residential land uses. Applying the same formula to all properties makes the process more proportional and potentially fairer. On the other hand, this method can be more difficult to manage, as it relies on accurate and regularly updated data on total impervious area, which includes developed area.

C) Using impervious areas for assessment (Methods 1.3, 1.4, and 2.2)

Using impervious areas to calculate fees makes the connection between runoff and cost stronger. As this method focuses on surfaces that do not absorb water, it reflects the potential environmental impact of each parcel more accurately. In the long run, it can encourage property owners to use more green space or reduce hard surfaces. Moreover, it can be part of cities' efforts to promote Low Impact Development (LID) strategies such as green roofs, permeable pavements, and rain gardens. On the other hand, this method requires high-quality and regularly updated data, again, on impervious surfaces, and added layer above and beyond just developed area. If the data becomes outdated or inconsistent, some areas (e.g., fast-growing or changing neighborhoods) might be unfairly represented.

D) Using building footprint/ developed area for assessment (Methods 1.1 to 1.3)

Using BAU based on building footprints offers an accessible method for calculating stormwater fees, as the required data is usually available, and any changes to buildings typically require official permits and reassessment, which improves data reliability. This method also requires fewer technical adjustments compared to full impervious surface mapping. However, focusing only on developed areas does not encourage green or sustainable designs, and it cannot capture all parts of a parcel that contribute to stormwater runoff. Using developed areas also does not consider the parcel's total size in the calculation, which may create inequality for large parcels that contain only small buildings.

E) Using total land value for assessment (2.1)

The data for this method is usually reliable and accessible, which makes it practical for calculating stormwater fees. However, since the fee is based on the total parcel value and not the actual amount of runoff, it may raise concerns about fairness. On the other hand, this method can remain more stable over time, because the total land area rarely changes. If regular data updates are difficult for local authorities, this method may be more reliable than other land-based filters, such as impervious area or building footprint.

F) Tax exemptions (Method 2.1 and 2.2)

Excluding government-owned and nonprofit parcels from the taxable properties keeps the analysis legally sound and consistent with the California Constitution. It also simplifies revenue collection by removing the need for any financial support or transfers from government funds.

6 Future Recommendations

This research explored the distributional and affordability impacts of various stormwater funding schemes in the City of Riverside. Although the primary goal of these methods was to illustrate the impact of different revenue-generation schemes on parcel expenditures and affordability, as well as how those impacts differ across adjustments to these methods, some additional issues that fall beyond the scope of this analysis yet may be useful to consider.

First, within the property-based taxation method, future work may consider applying different $ rates to residential and commercial parcels. This refinement, although it requires additional legal and administrative frameworks, could be of interest if there one wants to tax residential customers differently than commercial and/or industrial customers.

Second, a combination of physical and economic variables, such as property value and impervious area, might be explored in future studies. To achieve this, a weighted formula could be developed using a coefficient to balance runoff contribution and financial capacity in a single model. This hybrid scheme could combine the strengths of both methods, offering a broader view of fairness.

Furthermore, and with current concern and interest surrounding affordability and low-income households, we suggest evaluating the impact of excluding vulnerable households (e.g., low-income residents) from the program at the initial planning stage and understanding how the financial burden would be spread out across the remaining entities. This approach could reduce financial burden to lower income households while simultaneously increasing it on other types of property owners.

Finally, in Figure A1.1, Group B under Method 1 includes Multi-Family Housing, Mobile Home Parks, Churches, and Schools. These non-residential properties were subject to the parcel tax in Method 1, and all sub-methods show a relatively wide affordability range. In contrast, under Method 2, Churches and Schools were exempted, and the affordability range for Group B appears more limited. Further research is needed to determine whether this narrowing is attributable to tax exemptions.

Considering any of these changes in future studies could provide new insights for policymakers to improve stormwater finance mechanism design.

7 Acknowledgment

We would like to thank the UCR School of Public Policy Center for Community Solutions for providing financial support for this research.

We sincerely appreciate the collaboration with City of Riverside staff, especially Kevin Street, Stormy Osifeso, and Nathan Mustafa, for their participation in meetings and support during the analysis.
Special thanks to Janet Reyes for her assistance with GIS and technical challenges, and to Karen Jordan from Riverside County Information Technology for helping with data access.

Appendices 1

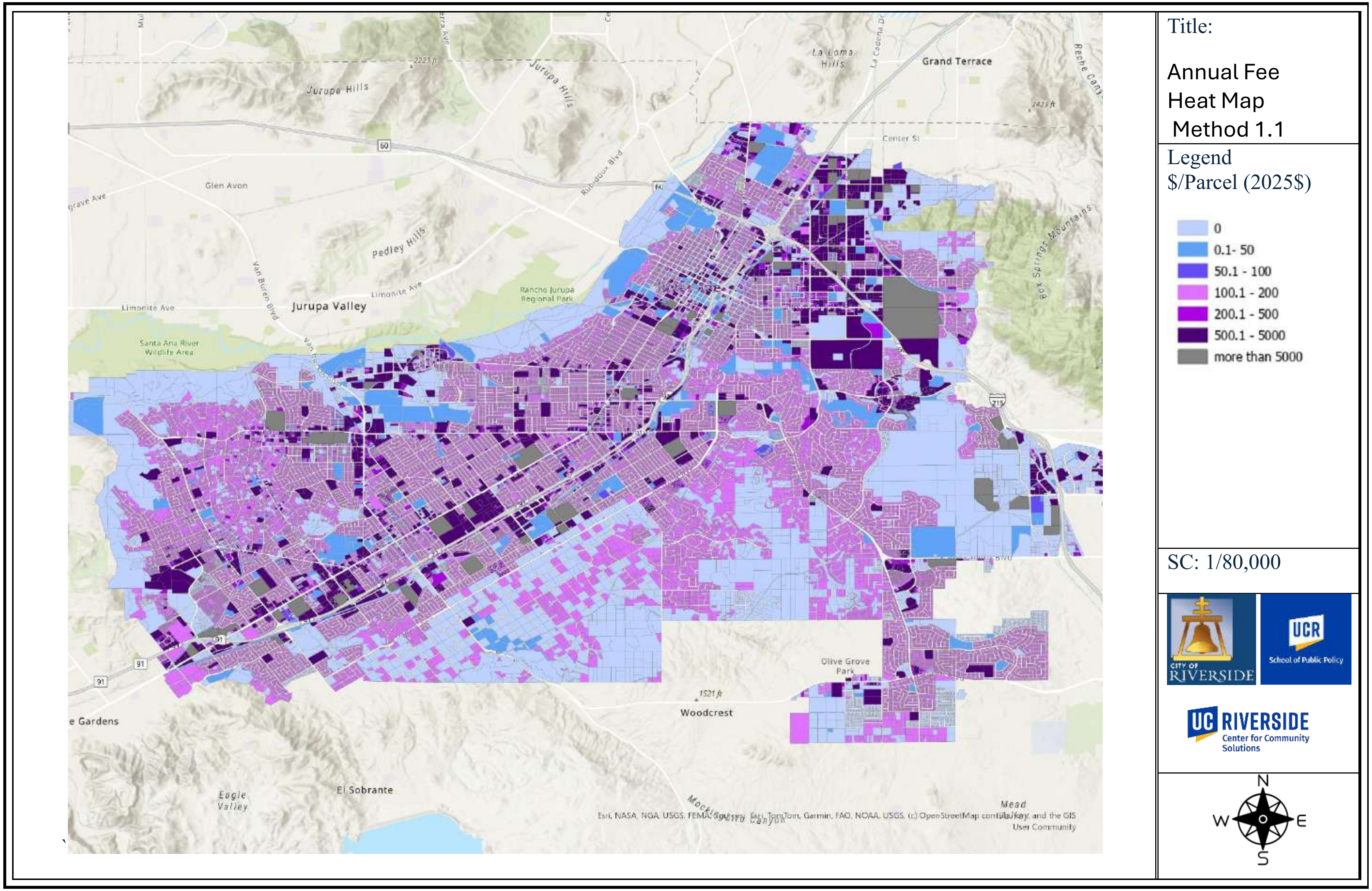
Table A1.1- Annual fee assessment (Parcel- level)

Statistic	Method 1- Parcel tax scheme				Statistic	Method 2 – Property tax scheme	
	1.1[*a and c]	1.2[*a]	1.3[*b and c]	1.4[*b]		2.1	2.2[*d]
$ rate per BAU	124.82	234.52	66.87	74.10	$ rate	0.000237649	0.0003888087
Mean	132.35	132.35	132.35	132.35	Mean	138.64	166.73
Std. Dev	376.62	718.74	968.21	1079.66	Std. Dev	649.97	953.27
Min	0.00	0.00	0.00	0.00	Min	0.00024	0.00000044
Q1	124.82	56.64	66.87	0.00	Q1	50.23	44.33
Median	124.82	72.87	66.87	42.53	Median	86.16	81.76
Q3	124.82	90.17	66.87	64.06	Q3	129.62	137.76
Max	37018.49	69553.77	106972.97	118541.94	Max	73,352.70	120,009.60
Skewness	41.21	39.96	46.72	45.95	Skewness	44.99	55.31
IQR[*e]	0.00	33.53	0.00	64.06	IQR	79.38	93.43

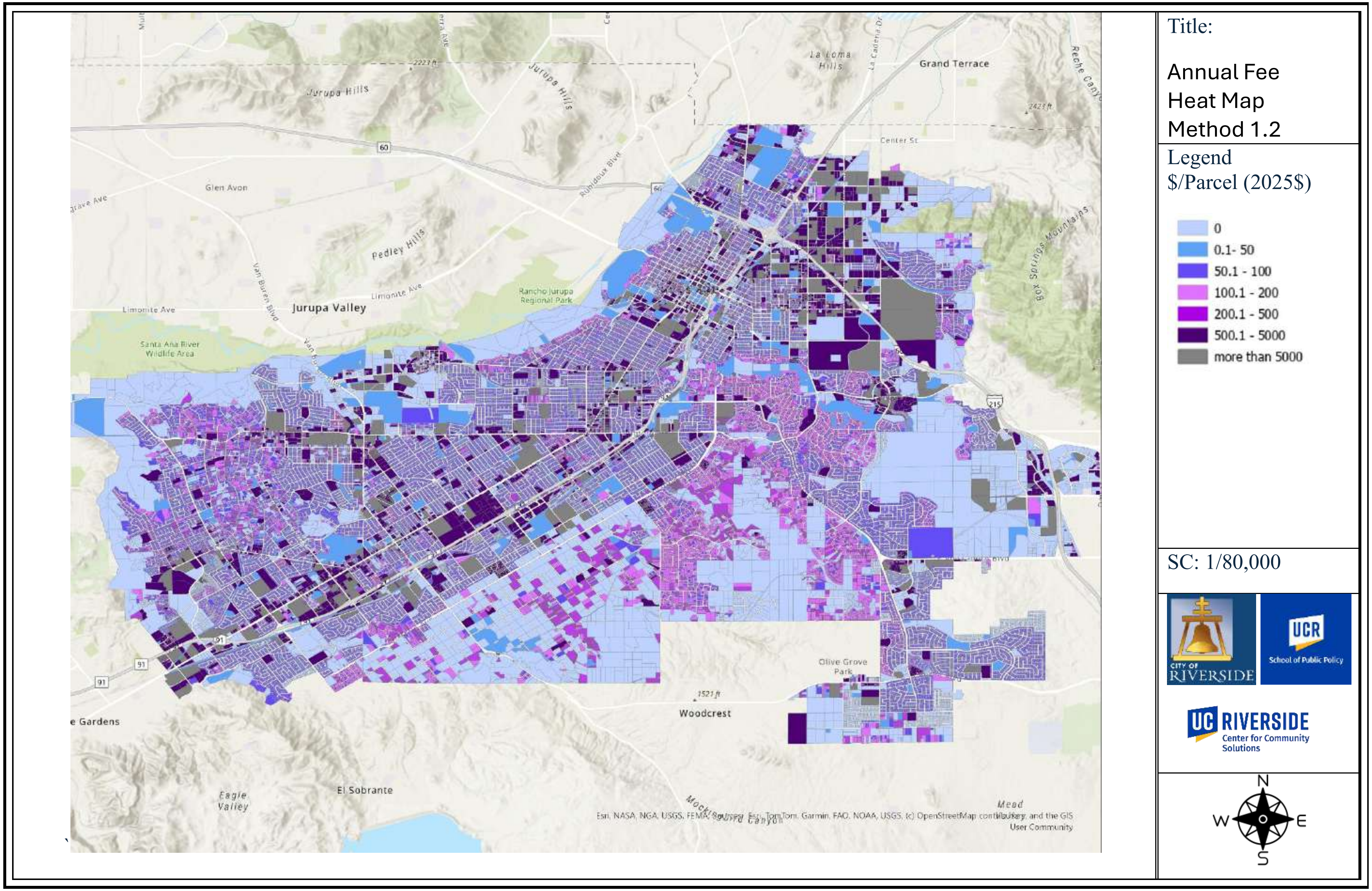
*Notes:

a- Methods 1.1 & 1.2: BAU calculation based on the developed area
b- Methods 1.3 & 1.4: BAU calculation based on impervious area
c- Methods 1.1 & 1.3: assume residential parcels = 1 BAU
d- Method 2.2: adjusts property values by impervious area
e- The interquartile range (IQR): Q3 - Q1

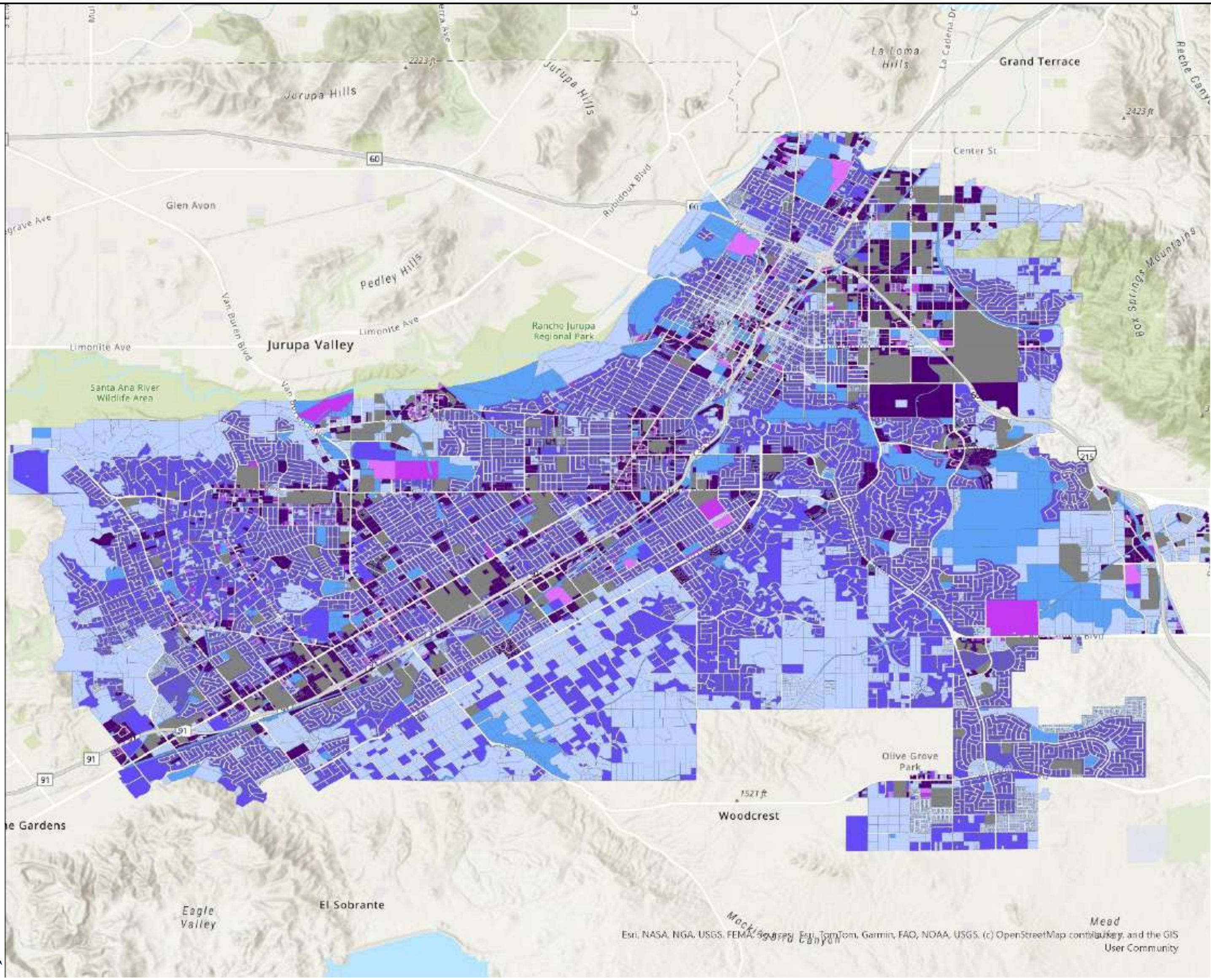
Map A1.1- Annual fee Method 1.1



Map A1.2- Annual fee Method 1.2



Map A1.3- Annual fee Method 1.3



Title:

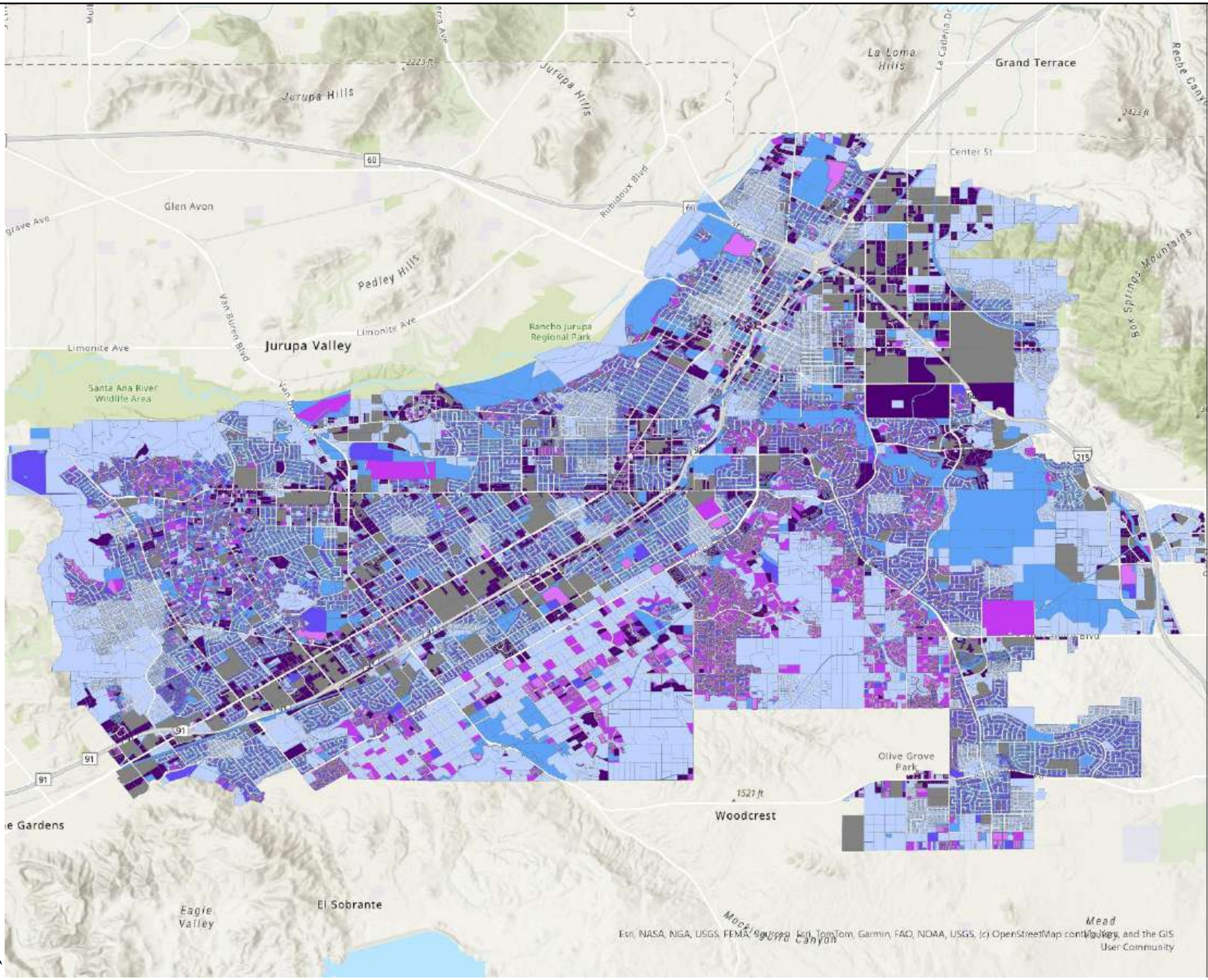
Annual Fee Heat Map Method 1.3

Legend
$/Parcel (2025$)

- 0
- 0.1- 50
- 50.1 - 100
- 100.1 - 200
- 200.1 - 500
- 500.1 - 5000
- more than 5000

SC: 1/80,000

Map A1.4- Annual fee Method 1.4



Title:

Annual Fee Heat Map Method 1.4

Legend
$/Parcel (2025$)

- 0
- 0.1- 50
- 50.1 - 100
- 100.1 - 200
- 200.1 - 500
- 500.1 - 5000
- more than 5000

SC: 1/80,000

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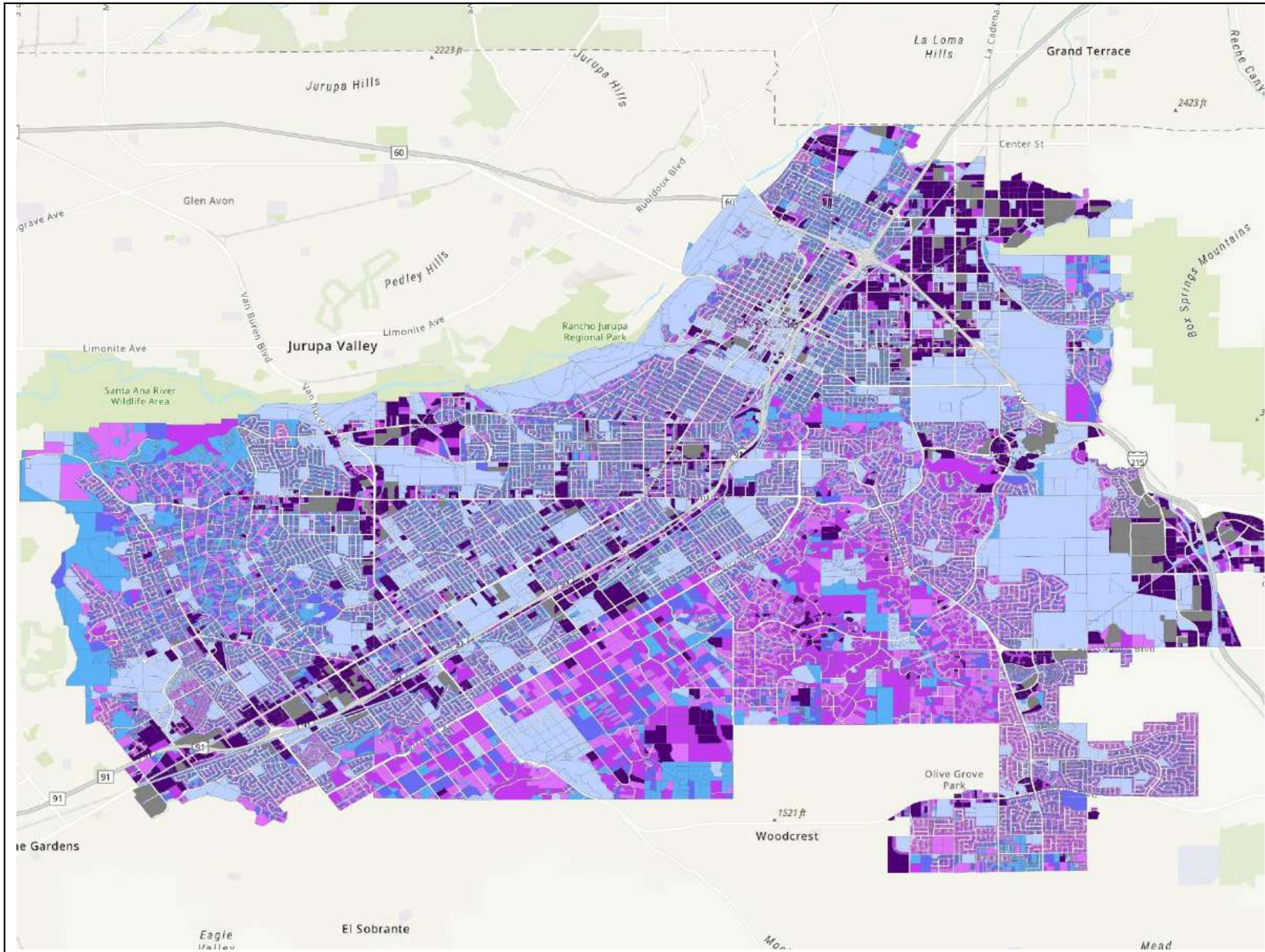
Map A1.5- Annual fee Method 2.1



Title:

Annual Fee Heat Map Method 2.1

Legend
$/Parcel (2025$)

- 0.0
- 0.1 - 50.0
- 50.1 - 100.0
- 100.1 - 200.0
- 200.1 - 500.0
- 500.1 - 5000.0
- More than 5000

SC: 1/80,000

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Map A1.6- Annual fee Method 2.2

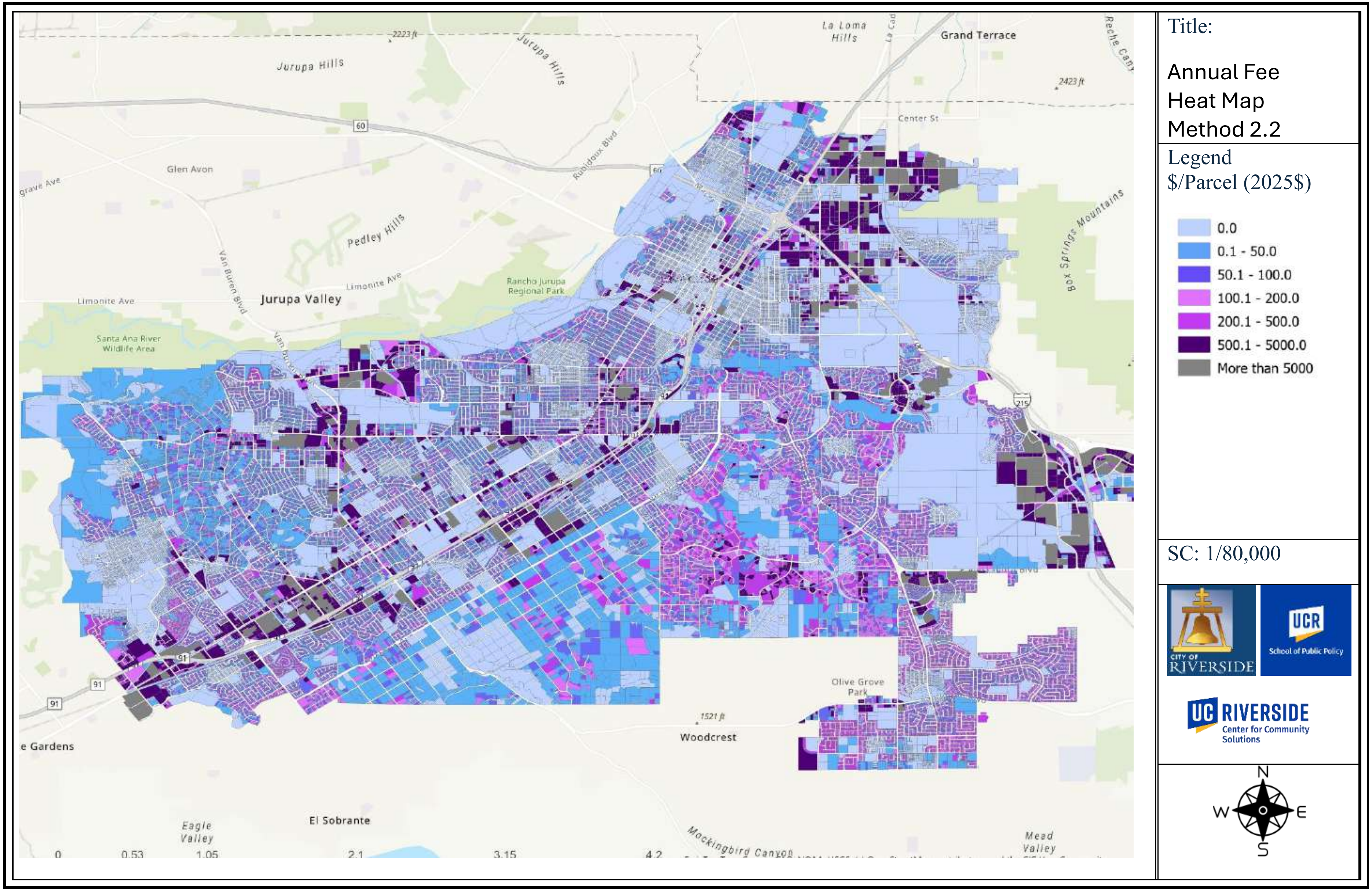


Table A1.2- Affordability analyses (Parcel- level)

Method 1	Income Metric	Max%	Q1%	Median %	Mean %	Q3%	SD%	Count >10%	Count Group B[*a and c]	Count Group C[*a and c]	Total Groups B & C	Count >2.5%	Count Group B[*a and c]	Count Group C[*a and c]	Total Groups B & C
1.1	MHI%	62.75	0.08	0.12	0.15	0.16	0.52	28	6	0	6	325	98	0	98
	20th%	189.19	0.14	0.20	0.45	0.42	1.92	205	57	0	57	929	234	0	234
1.2	MHI%	117.89	0.05	0.07	0.16	0.10	1.01	119	26	3	29	650	183	15	198
	20th%	355.47	0.09	0.15	0.48	0.28	3.59	446	117	12	129	1596	400	38	438
1.3	MHI%	96.32	0.04	0.06	0.17	0.08	1.24	152	27	0	27	752	186	0	186
	20th%	670.95	0.08	0.11	0.50	0.22	4.91	577	123	0	123	1643	333	0	333
1.4	MHI%	106.73	0.00	0.04	0.17	0.07	1.39	179	32	6	38	832	196	20	216
	20th%	743.51	0.00	0.08	0.50	0.17	5.46	653	134	15	149	1793	351	56	407
Method 2	Income Metric	Max%	Q1%	Median %	Mean %	Q3%	SD%	Count >10%	Count residential[*b and c]			Count >2.5%	Count residential[*b and c]		
2.1	MHI%	92.7	0.04	0.08	0.15	0.12	0.88	86	N/A	N/A	23	404	N/A	N/A	94
	20th%	768.0	0.08	0.16	0.44	0.30	4.14	314	N/A	N/A	62	1510	N/A	N/A	558
2.2	MHI%	152	0.000	0.05	0.15	0.12	1.2	121	N/A	N/A	33	555	N/A	N/A	112
	20th%	1257	0.000	0.14	0.46	0.26	5.85	426	N/A	N/A	83	1764	N/A	N/A	613

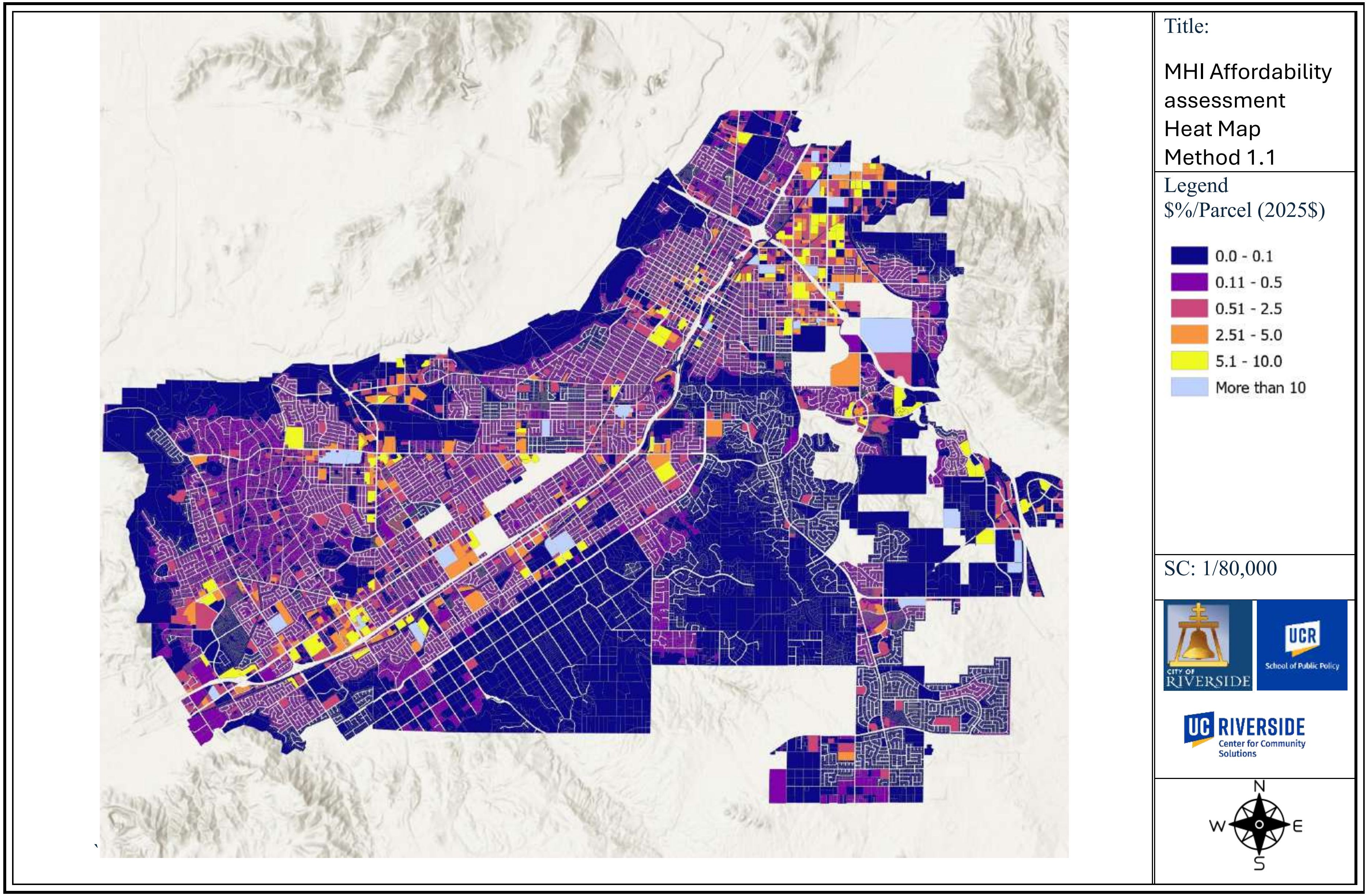
* Notes:

a- For method 1:
  - Group B Including multi-family residential parcels (see Table 1) - Total number of parcels in Group B = 5,878
  - Group C is single family residential (see Table 1) - Total number of parcels in Group C = 57,610

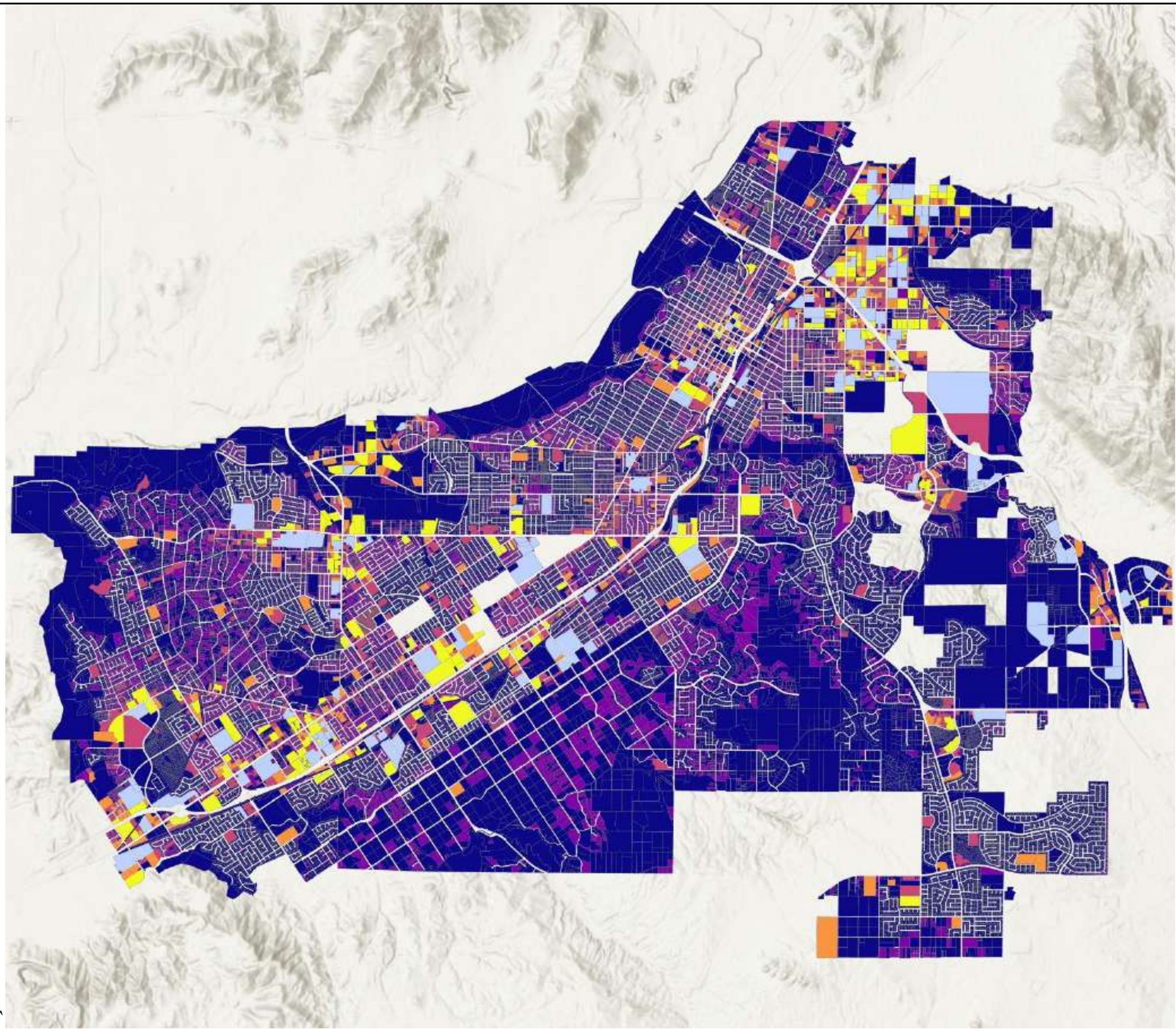
b- For method 2:
  - Total number of residential parcels (from dataset 2.1.2) for method 2
    - Single-Family Residential: 57,495
    - Multi-Family Residential: 5,539
    - Single-Family Residential/Agricultural: 115

c- Total number of parcels in the city: 75,563

Map A1.7- Affordability Assessment- MHI Method 1.1



Map A1.8- *Affordability Assessment- MHI Method 1.2*



Title:

MHI Affordability assessment Heat Map Method 1.2

Legend
$%/Parcel (2025$)

- 0.0 - 0.1
- 0.11 - 0.5
- 0.51 - 2.5
- 2.51 - 5.0
- 5.1 - 10.0
- More than 10

SC: 1/80,000

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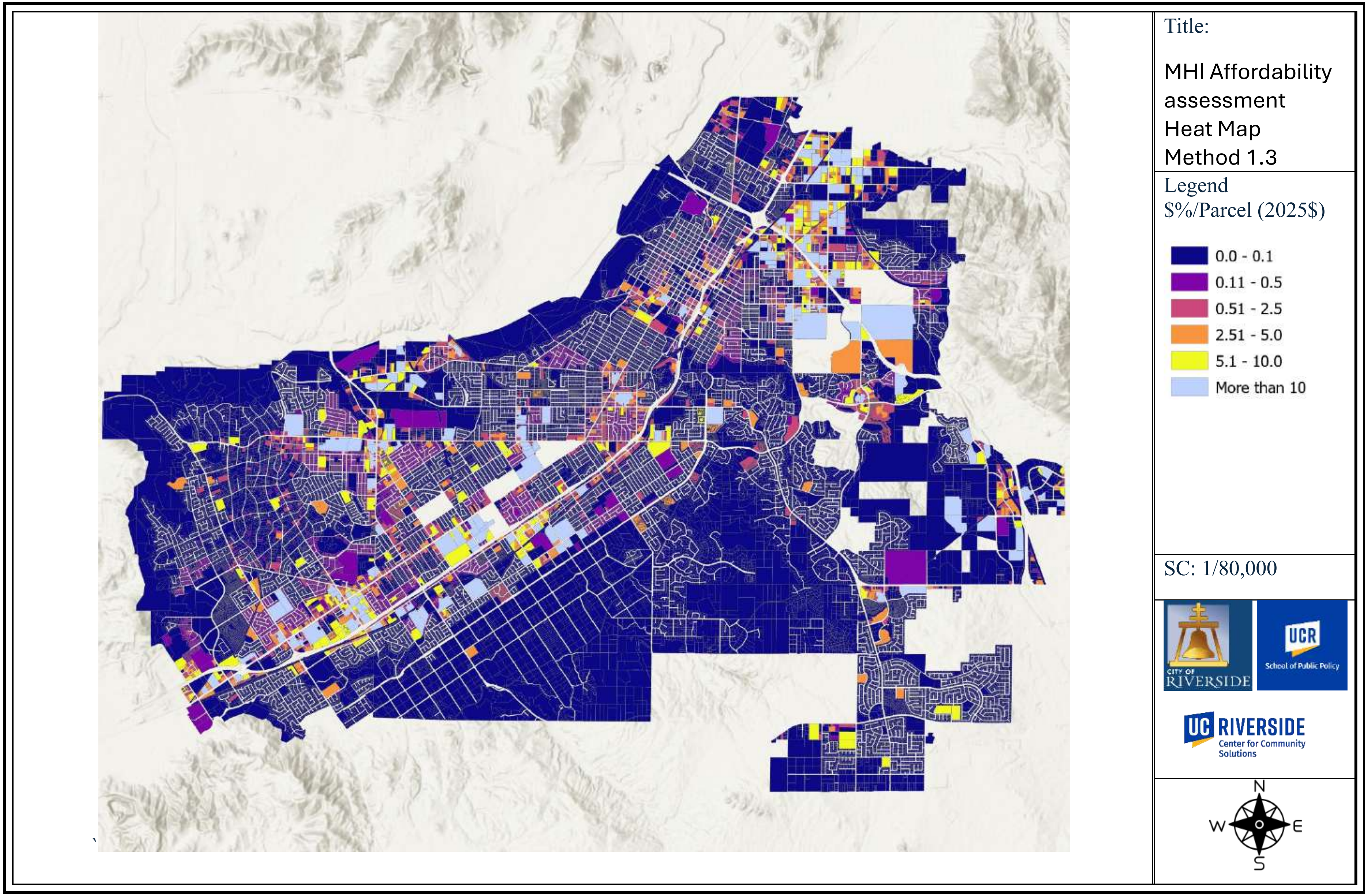
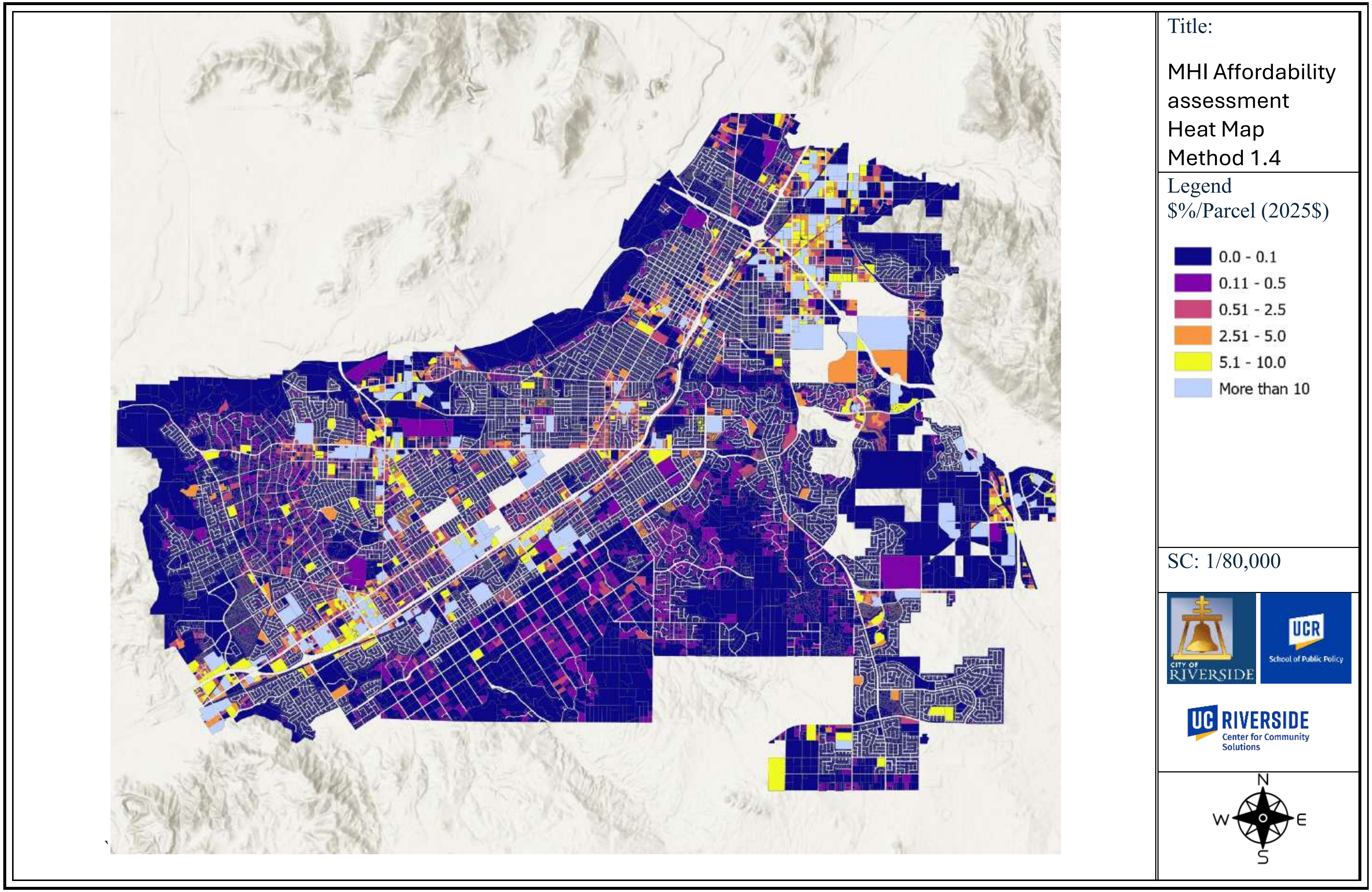
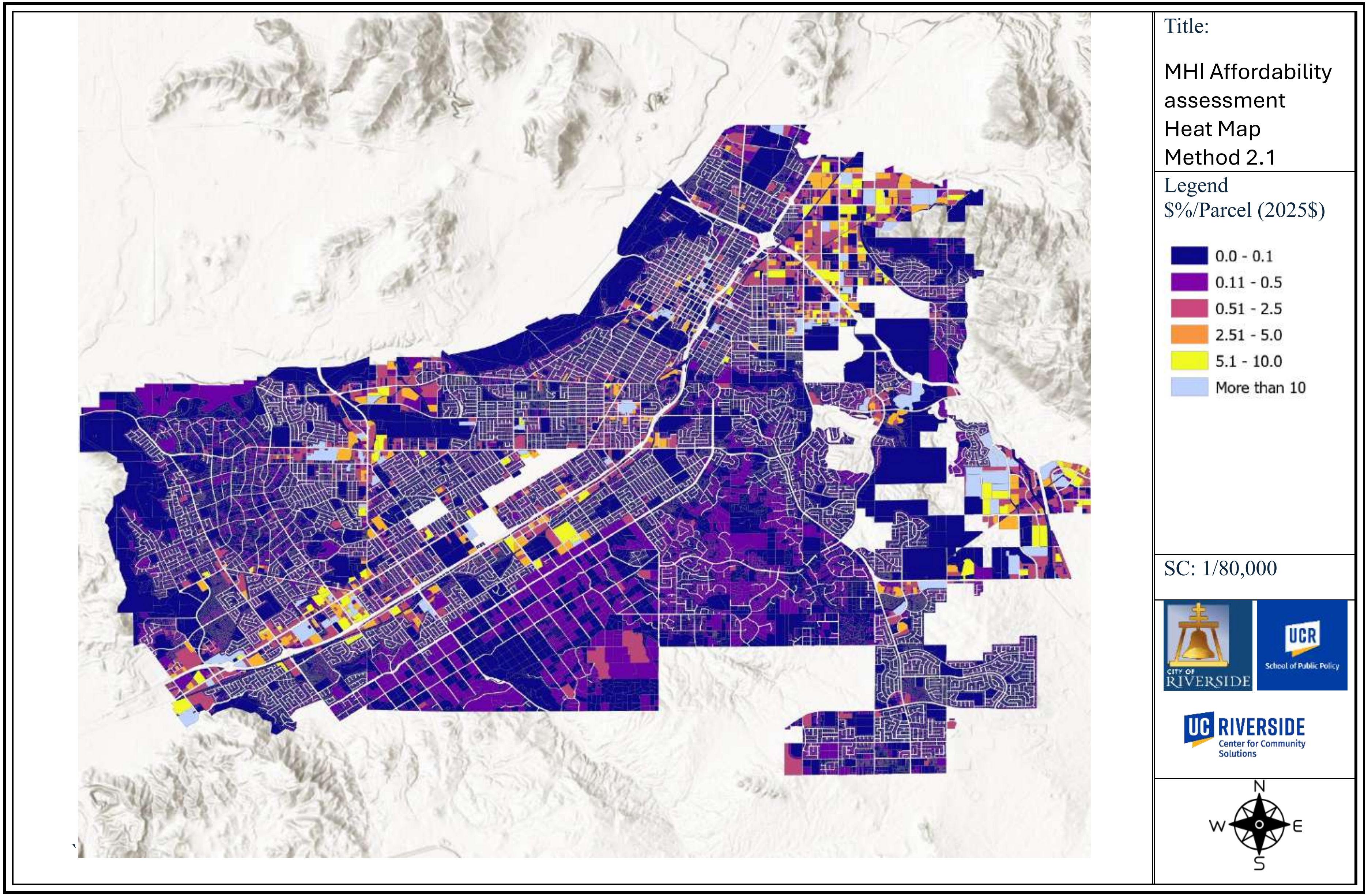
Map A1.9- Affordability Assessment- MHI Method 1.3



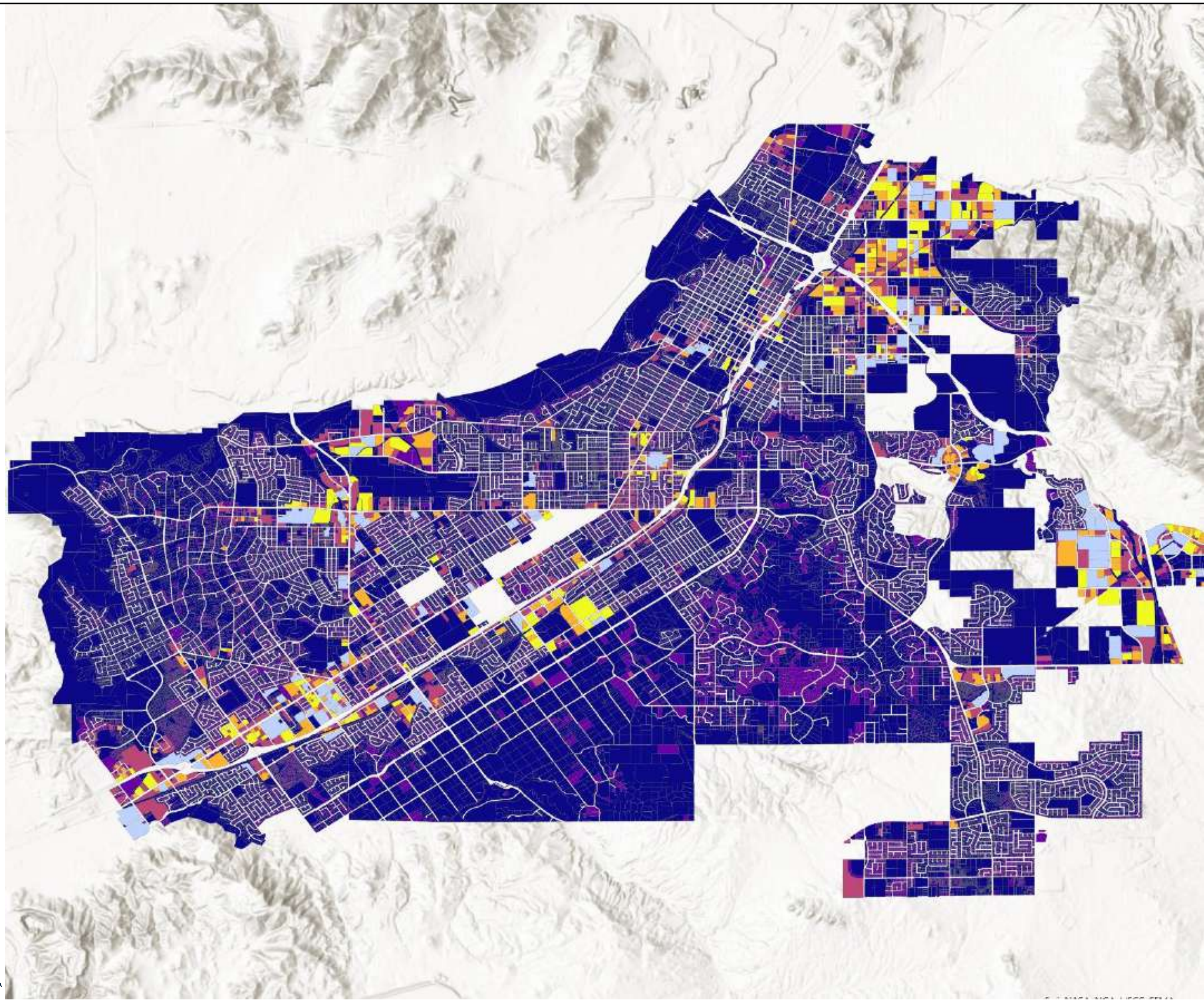
Map A1.10- Affordability Assessment- MHI Method 1.4



Map A1.11- *Affordability Assessment- MHI Method 2.1*



Map A1.12- *Affordability Assessment- MHI Method 2.2*



Title:

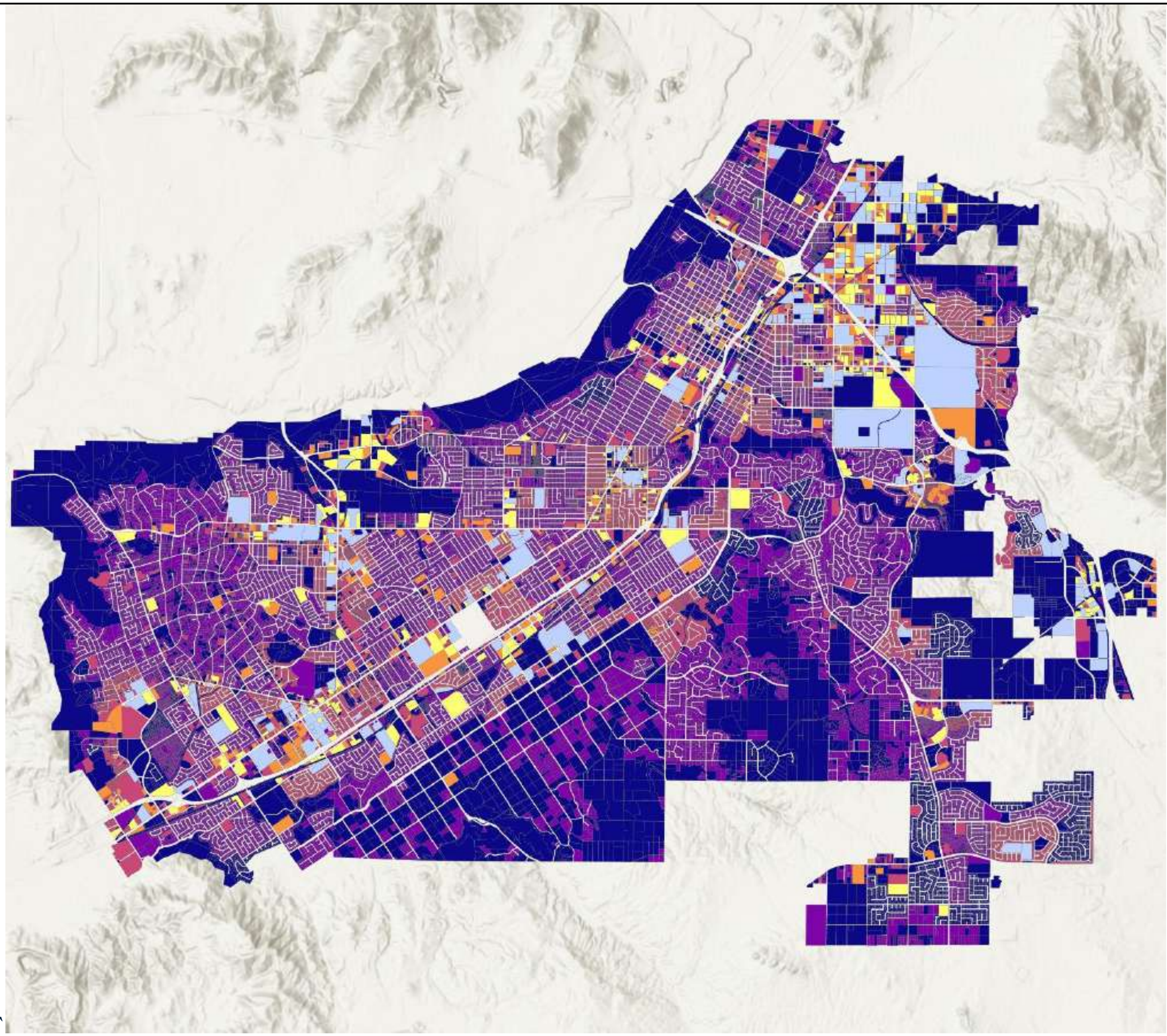
MHI Affordability assessment Heat Map Method 2.2

Legend
$%/Parcel (2025$)

- 0.0 - 0.1
- 0.11 - 0.5
- 0.51 - 2.5
- 2.51 - 5.0
- 5.1 - 10.0
- More than 10

SC: 1/80,000

Map A1.13- Affordability Assessment- 20^TH percentile- Method 1.1



Title:

20th percentile Affordability assessment Heat Map Method 1.1

Legend
$%/Parcel (2025$)

■	0.0 - 0.1
■	0.11 - 0.5
■	0.51 - 2.5
■	2.51 - 5.0
■	5.1 - 10.0
■	More than 10

SC: 1/80,000

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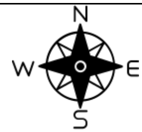
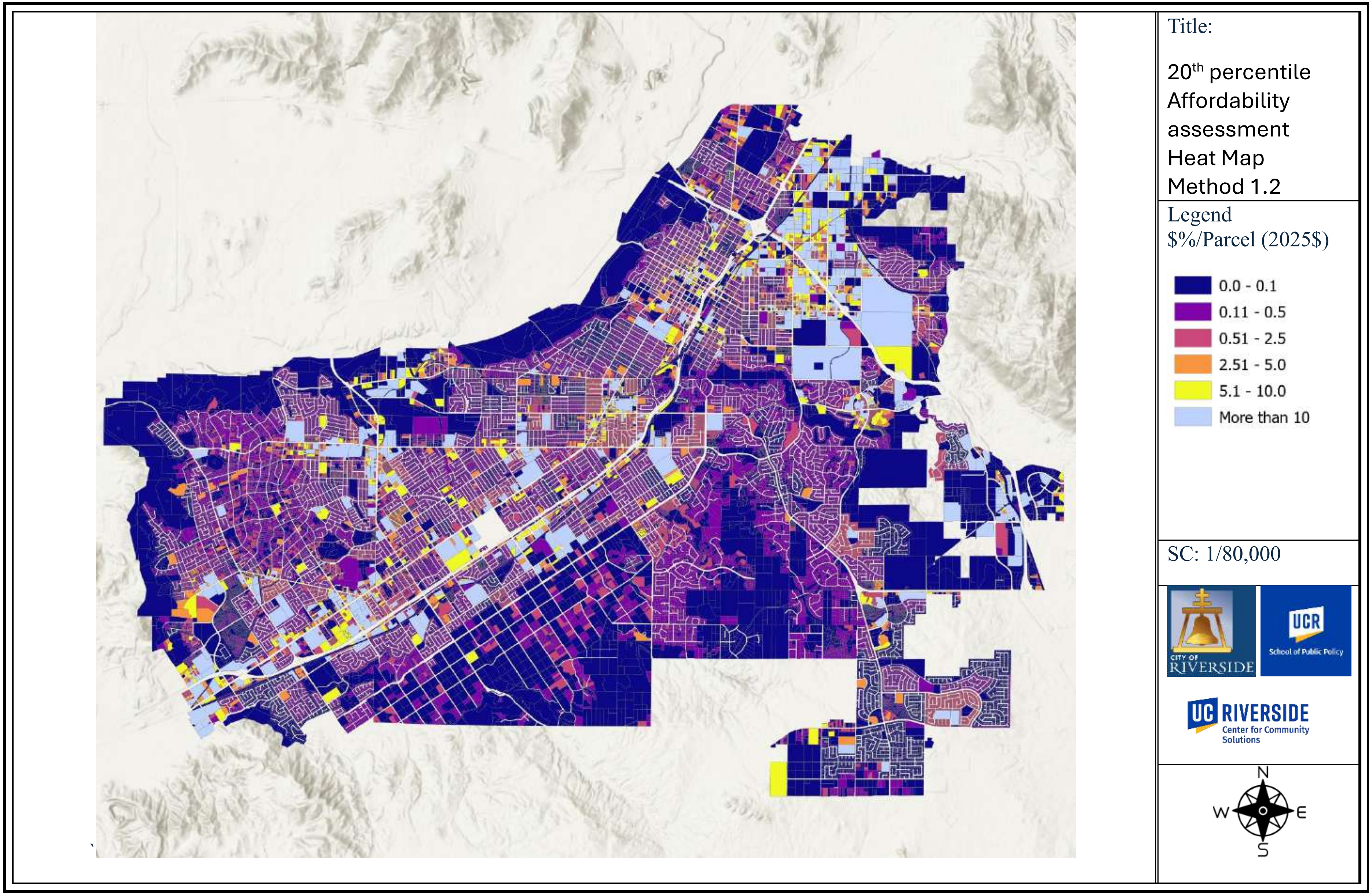
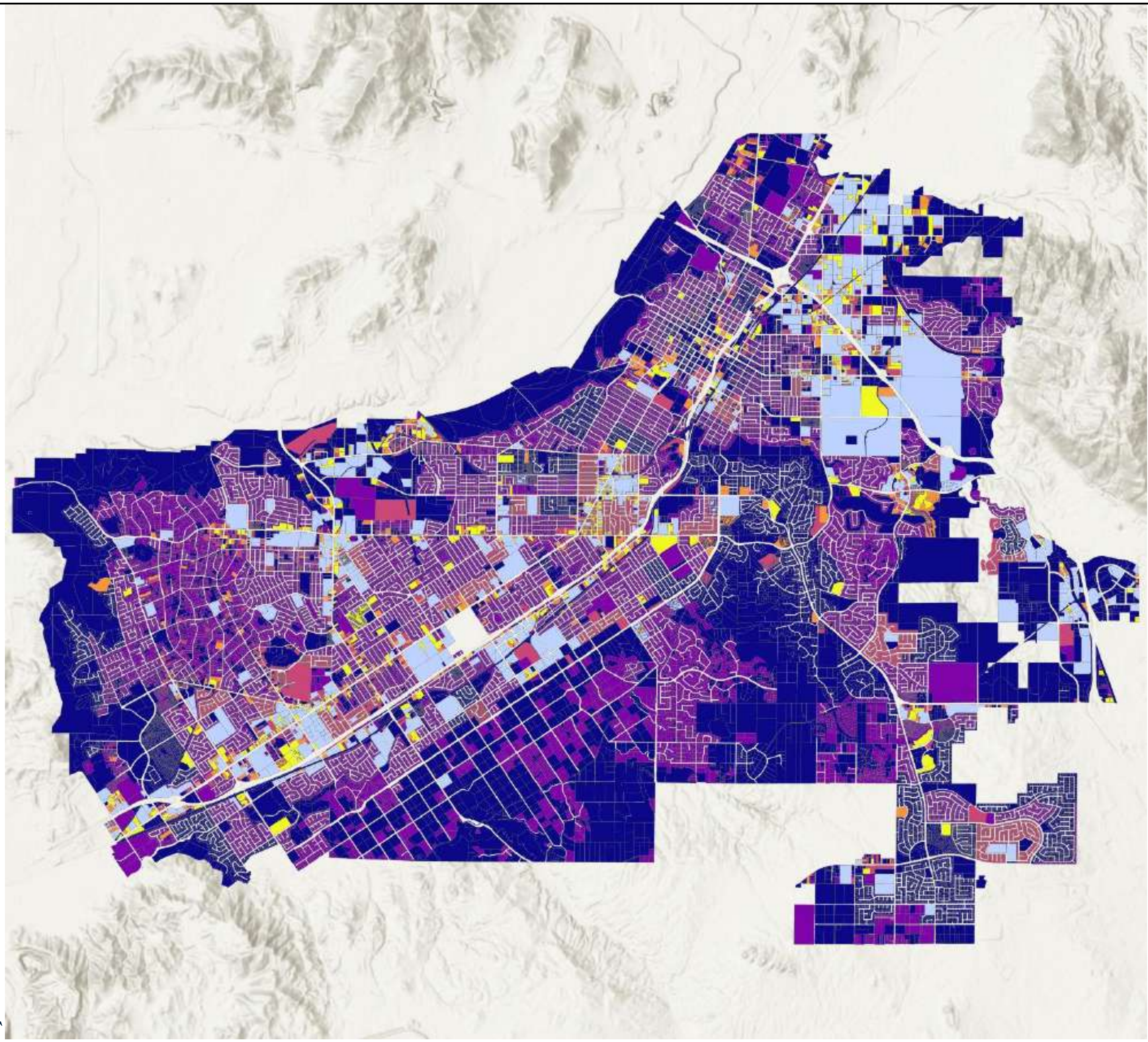


Map A1.14- Affordability Assessment- 20TH percentile- Method 1.2



Map A1.15- *Affordability Assessment- 20^{TH} percentile- Method 1.3*



Title:

20th percentile Affordability assessment Heat Map Method 1.3

Legend
$%/Parcel (2025$)

- 0.0 - 0.1
- 0.11 - 0.5
- 0.51 - 2.5
- 2.51 - 5.0
- 5.1 - 10.0
- More than 10

SC: 1/80,000

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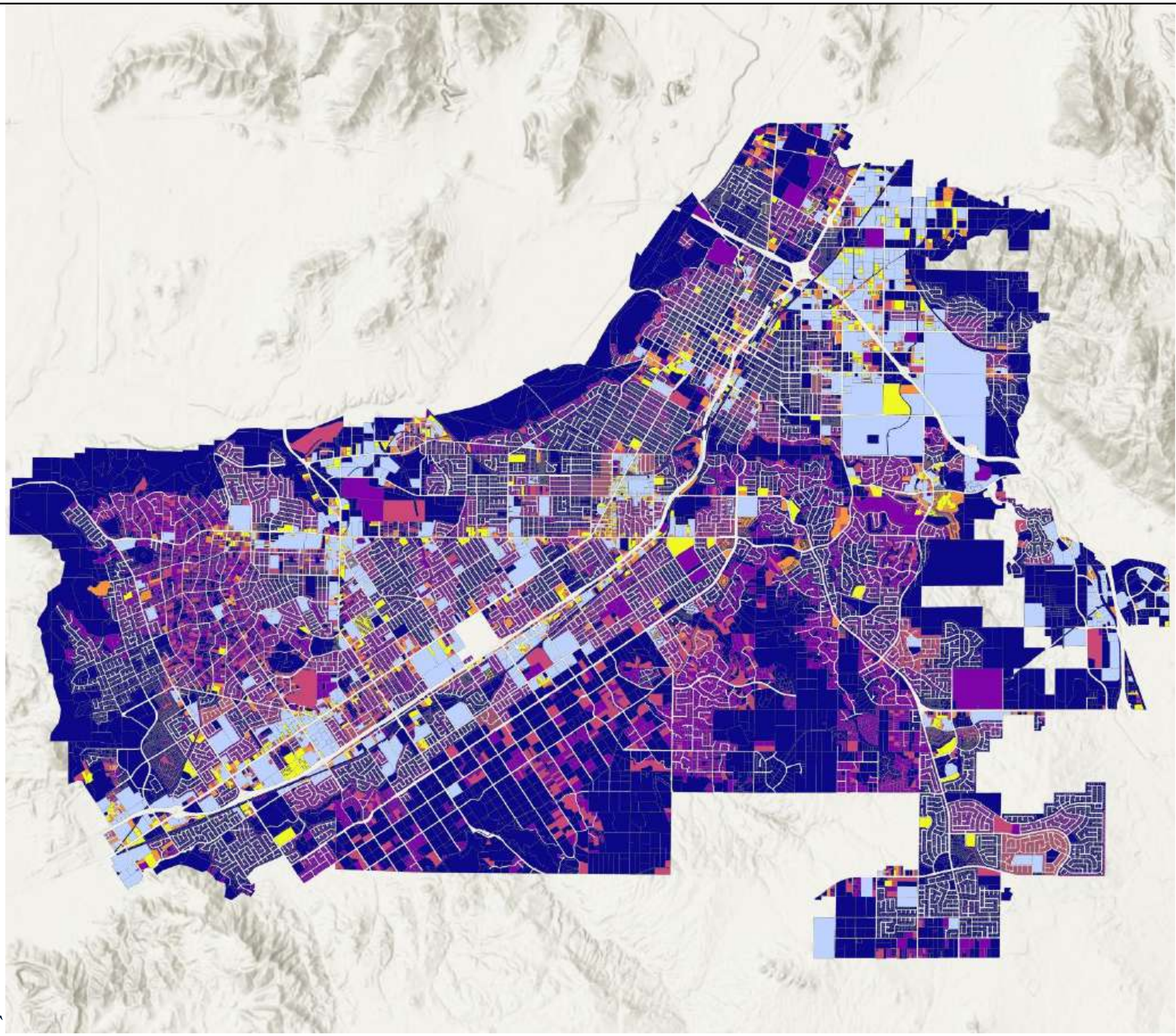
Map A1.16- Affordability Assessment- 20^{TH} percentile- Method 1.4



Title:

20th percentile Affordability assessment Heat Map Method 1.4

Legend
$%/Parcel (2025$)

■	0.0 - 0.1
■	0.11 - 0.5
■	0.51 - 2.5
■	2.51 - 5.0
■	5.1 - 10.0
■	More than 10

SC: 1/80,000

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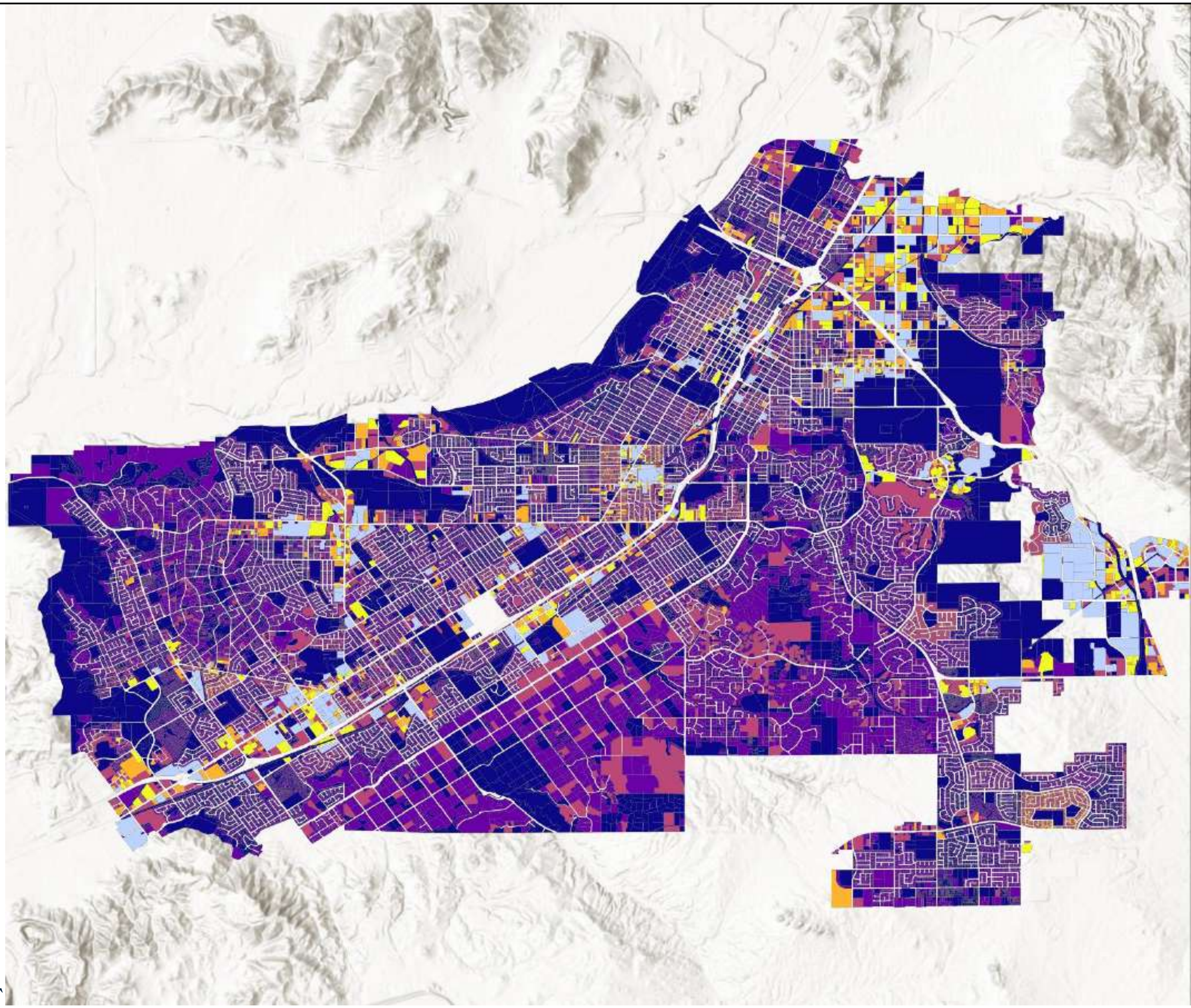
Map A1.17- Affordability Assessment- 20TH percentile- Method 2.1



Title:

20th percentile Affordability assessment Heat Map Method 2.1

Legend
$%/Parcel (2025$)

- 0.0 - 0.1
- 0.11 - 0.5
- 0.51 - 2.5
- 2.51 - 5.0
- 5.1 - 10.0
- More than 10

SC: 1/80,000

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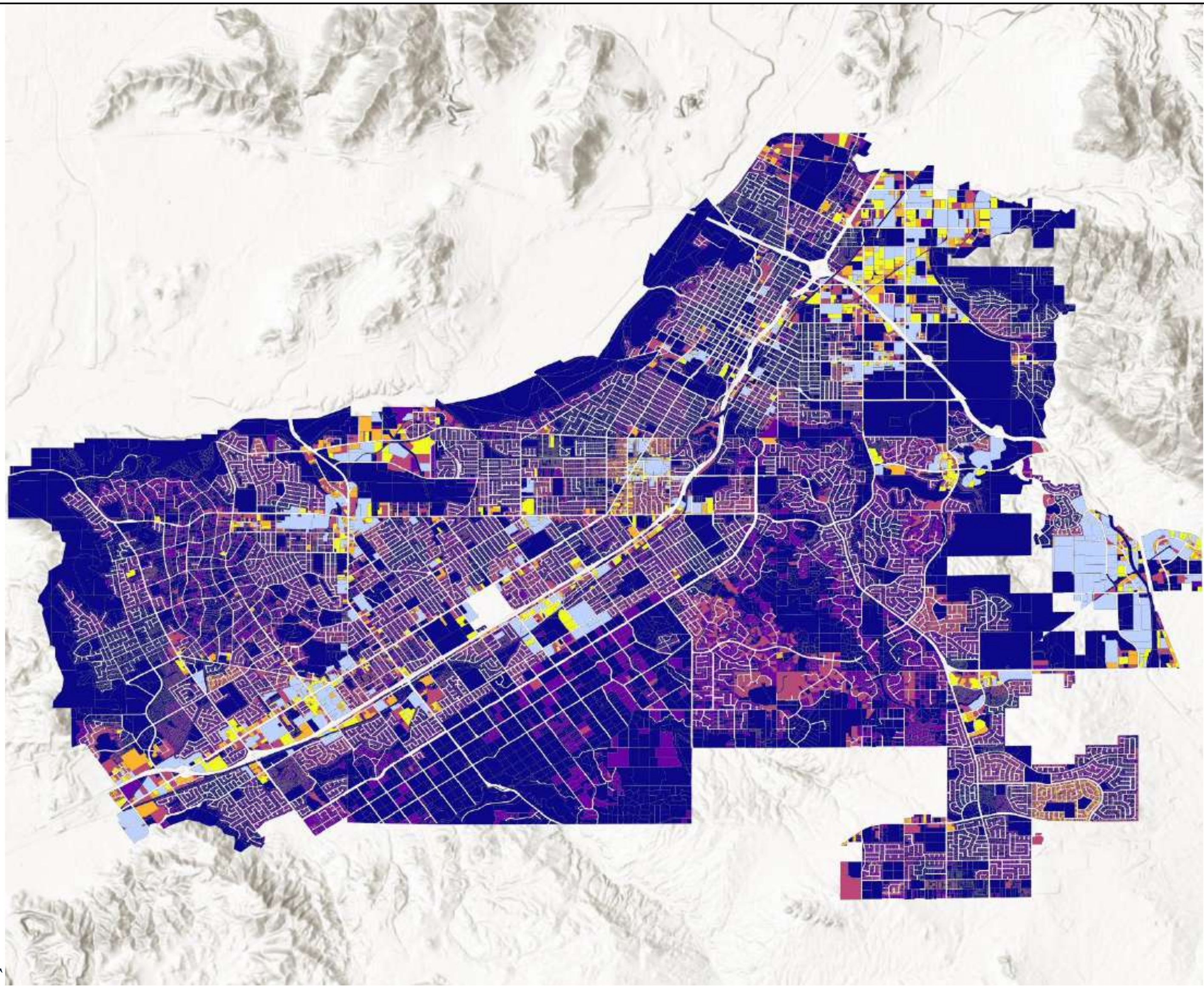
Map A1.18- Affordability Assessment- 20TH percentile- Method 2.2



Title:

20th percentile Affordability assessment Heat Map Method 2.2

Legend
$%/Parcel (2025$)

- 0.0 - 0.1
- 0.11 - 0.5
- 0.51 - 2.5
- 2.51 - 5.0
- 5.1 - 10.0
- More than 10

SC: 1/80,000

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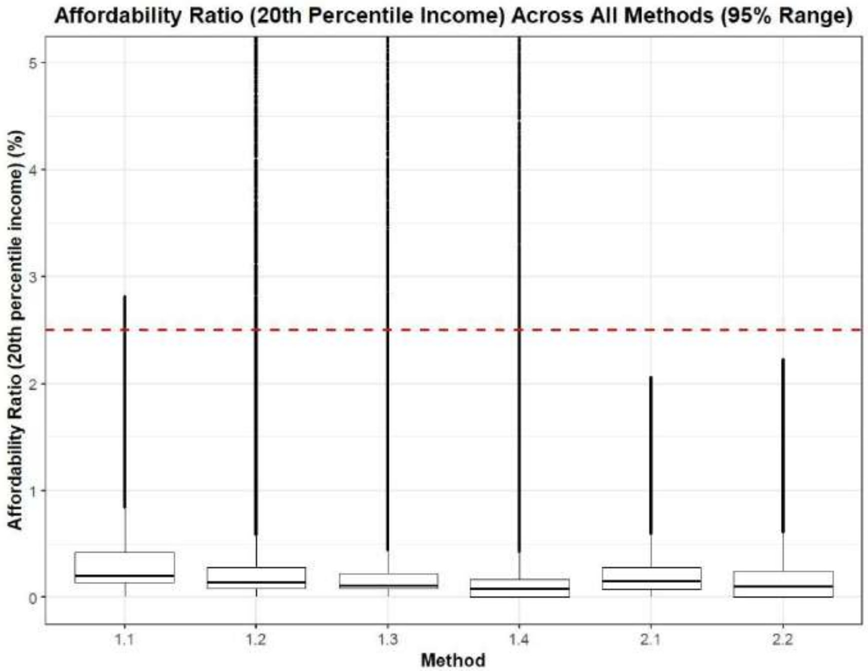
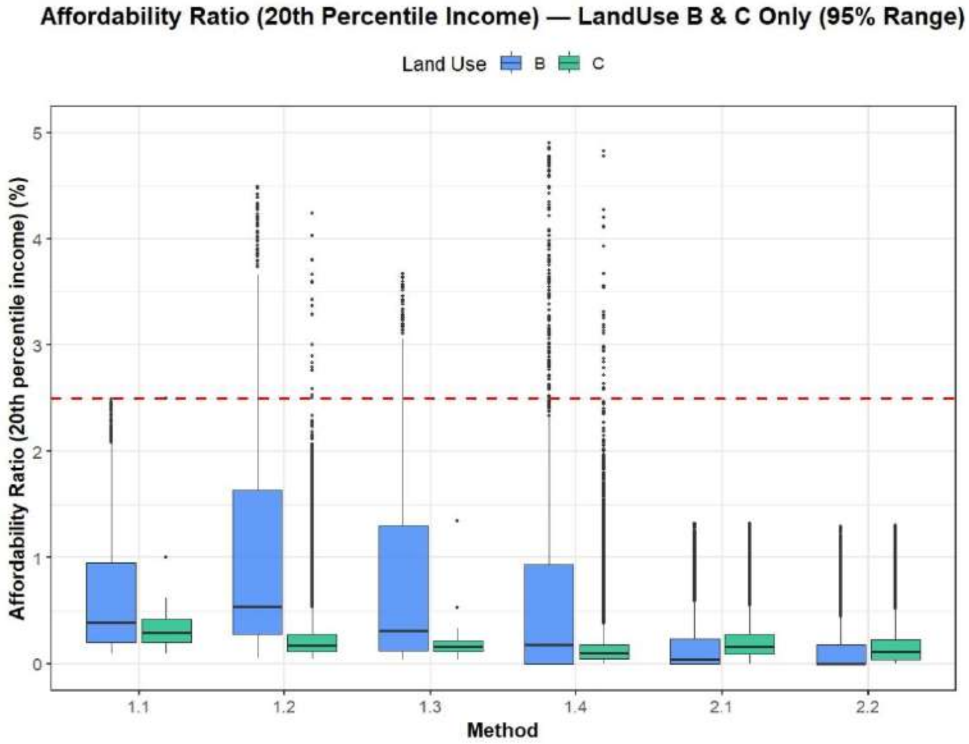
Figure A1.1- Affordability Ratio (20th percentile income)

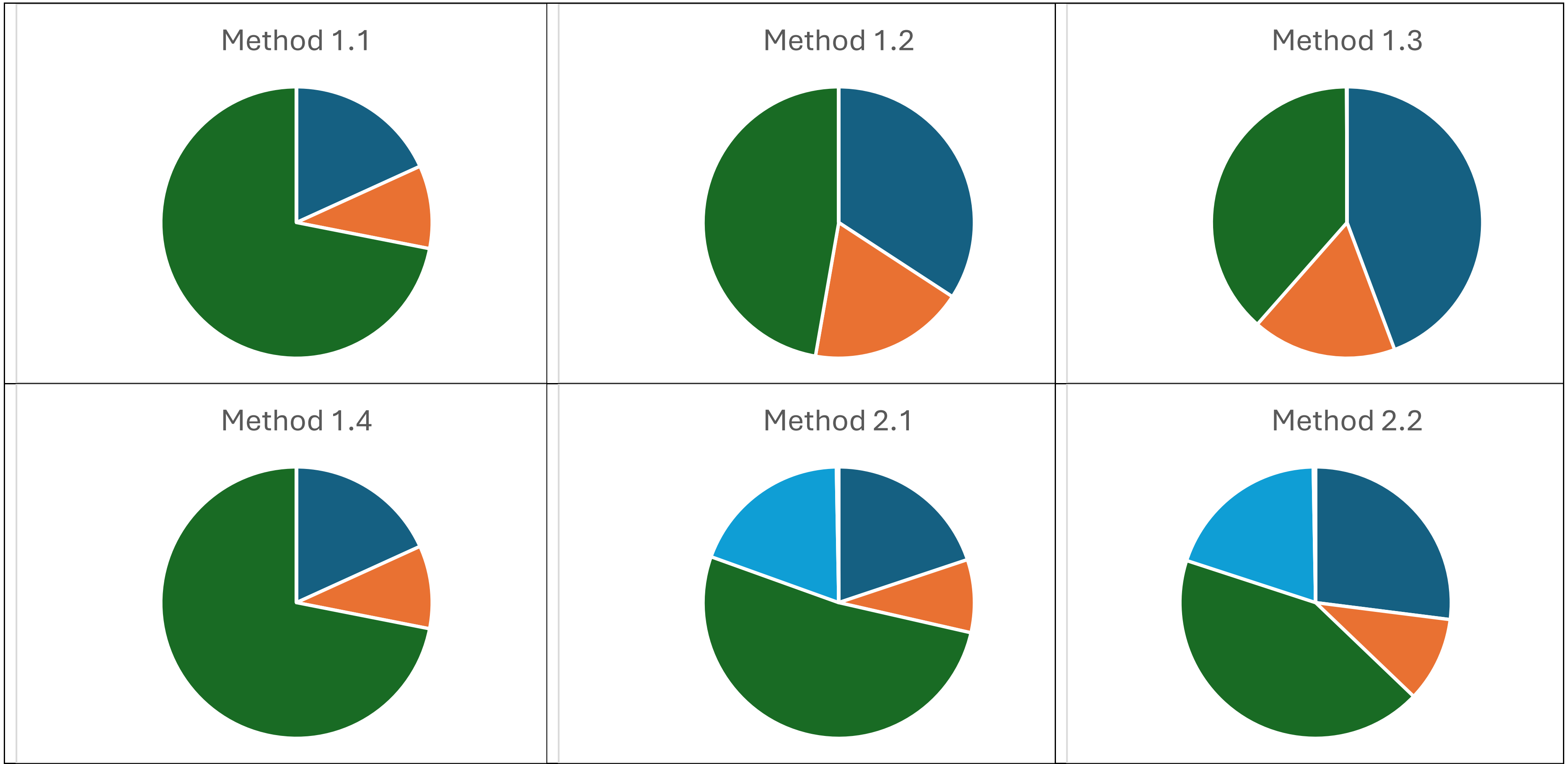




Notes:

- The left panel illustrates the affordability ratio for all land-use categories.
- The right panel presents the same information but filtered for residential parcels (LandUse groups B and C).
- The red dashed line represents the affordability threshold of 2.5%, above which parcels are considered financially stressed under the assessed stormwater fee.
- Each boxplot shows the distribution of parcel-level affordability ratios: the box spans the interquartile range (25th–75th percentile), the horizontal line inside each box marks the median, and the whiskers extend to the most extreme data points within 1.5×IQR of the box limits.

Figure A1.2- Share of annual fee contributions by land use group across sub-methods



Legend	Groups % (see Table 1)		Land uses	Sub-methods 1.1	1.2	1.3	1.4	2.1	2.2
		A	Commercial and Industrial properties	18.2	34.2	44.3	49.1	19.87	27.00
		B	Multi-Family Housing, Mobile Home Parks, Churches, and Schools	9.89	18.55	17.2	19	8.70	10.15
		C	Single-Family Residential parcels	71.9	47.23	38.45	31.9	51.92	42.87
		D	Agricultural and Vacant parcels	0	0	0	0	19.23	19.70
		E	Golf Courses and Private Parks	0.002	0.001	0.007	0.008	0.15	0.23
		F	Miscellaneous parcels with minor structures	0.008	0.019	0.042	0.047	0.13	0.05

Appendices 2

1- Initial GIS Method for Impervious Area Detection

At the beginning of the study, we tried to estimate the impervious surface by categorizing NAIP[12] 2022 aerial photos using GIS. For the purpose of calculating the Normalized Difference Vegetation Index (NDVI) and classifying land cover over the City of Riverside, the four-band raster dataset (i.e. Blue, Green, Red, and Near-Infrared) was processed in ArcGIS Pro. To get NDVI values between -1 and +1, other methods were used, such as the Band Arithmetic NDVI function and the Raster Calculator. Next, an unsupervised pixel-based classification was done (using the ISO Cluster tool in GIS), which grouped the image pixels into five color-based categories such as vegetation, soil, roofs, and paved areas. Notably, this is a common approach used in urban and environmental studies when higher-resolution or pre-processed datasets are not available[13].

Nevertheless, this approach was insufficient for accurate imperviousness identification at the parcel level. Table A2 1 shows the result of this classification. In this method, the impervious surfaces are represented by a range of grey shades. Since brown roofs and bare soil have similar spectral colors, the NDVI-based method frequently failed in classifying them. Furthermore, because NAIP images have a very high resolution (60 cm to 1 m), the raster files became extremely large and could not be exported in ArcGIS. To make them usable, the images had to be resampled to a coarser size, which reduced their spatial accuracy.

Table A2 1- Results of NDVI and classification method

	Tiff image of Riverside	NDVI and classification method
1 - Underestimating		
2 - Overestimating		

12 Source: California Department of Fish and Wildlife, GIS Map Services. Available at: https://wildlife.ca.gov/Data/GIS/Map-Services

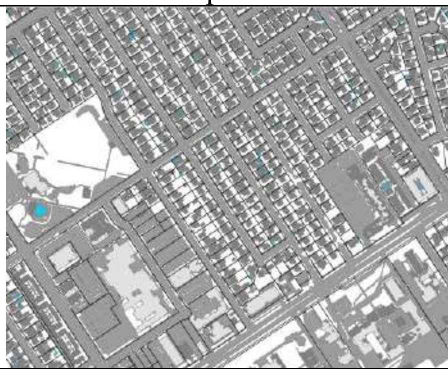
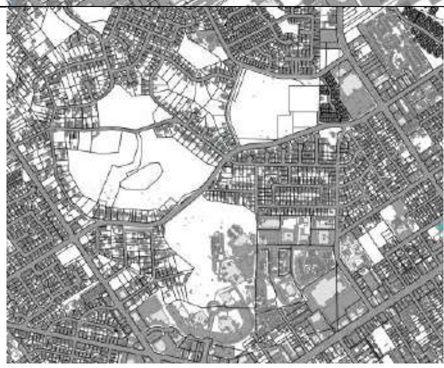
[13] e.g.: "Weng, Q. (2012). Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. Remote sensing of Environment, 117, 34-49" And "Xian, G., & Crane, M. (2005). Assessments of urban growth in the Tampa Bay watershed using remote sensing data. Remote sensing of environment, 97(2), 203-215."

2- Nearmap data source

This study used a dataset that the County of Riverside made accessible to the public upon request to improve the accuracy of impervious surface assessment at the parcel level. In 2023, Nearmap[14] created this dataset using artificial intelligence–based surface categorization algorithms. Then, the AI categorization was applied to high-resolution aerial imagery, with a pixel size of about 5–7 cm. As a result, this dataset contains detailed mapping of impervious areas, including asphalt, concrete slabs, building footprints, hard surfaces, and pools.

Using multispectral imagery, including near-infrared (NIR) bands, Nearmap's unique AI Packs can accurately distinguish between previous and impervious surfaces. This data source is one of the most accurate public resources for surface-type mapping, as it is frequently updated and validated across major U.S. cities. For this reason, the analysis in this study was based on this dataset, which proved to be both reliable and consistent. In Table A2 2, the results of this method are illustrated; similar to the previous method, the grey colors indicate impervious areas in this dataset.

Table A2 1- Results of Nearmap's method

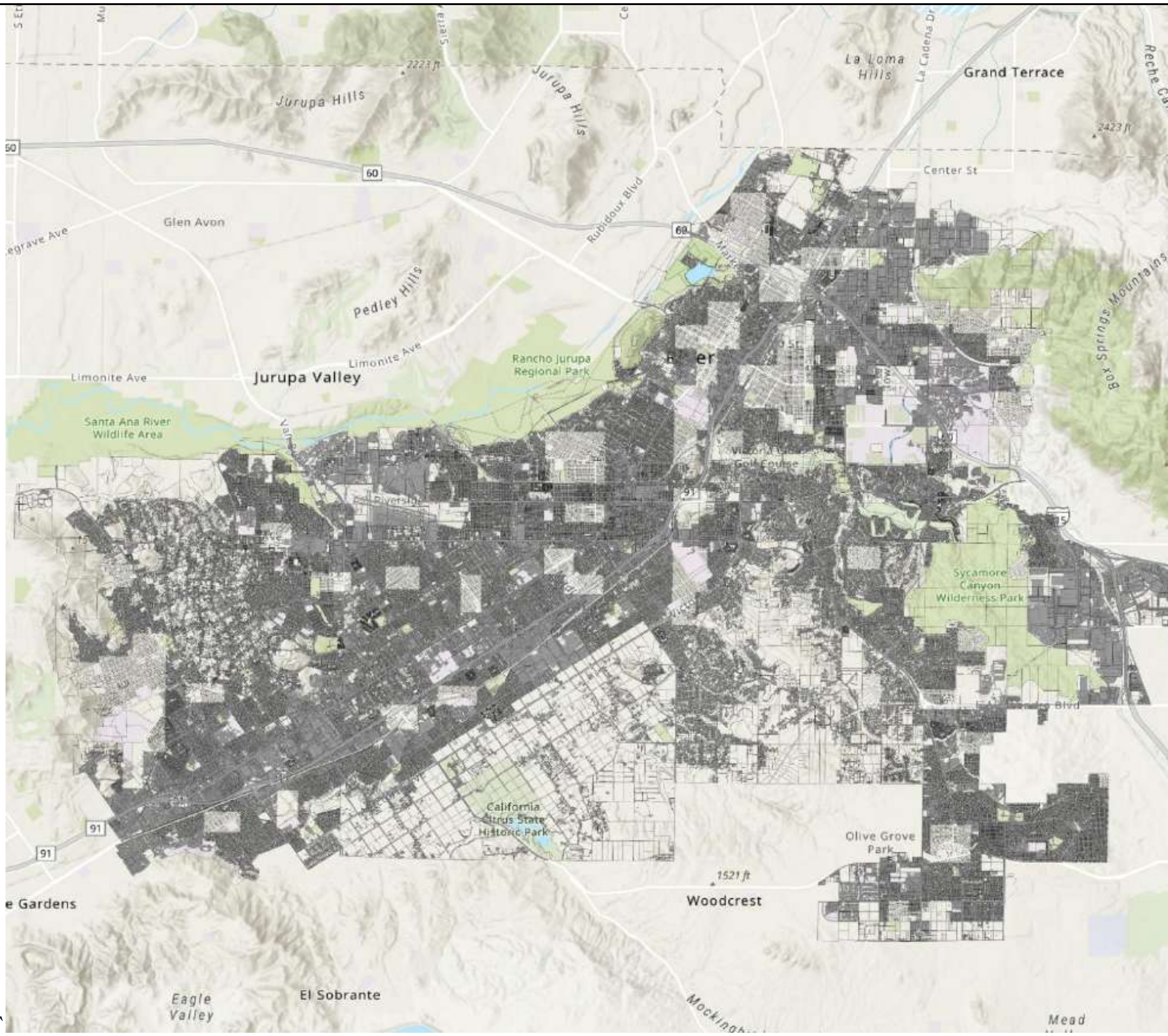
	Tiff image of Riverside	Nearmap's method
1 - Accurate		
2 - Accurate		

3- Comparison of the Two Methods

Maps A2 1 and A2 2 show the results of both methods. When looking at the City of Riverside (2,273,260,198 sq ft) as a whole, both methods yielded quite consistent spatial patterns. Nevertheless, the NDVI-based technique estimated 47.9% (1,088,932,934 sq ft) of the total impervious surface, while Nearmap reported roughly 39.1% (888,981,217 sq ft), with a difference of around 8.8% between two methods. However, regardless of these variations, both approaches agree that impervious areas cover less than half of Riverside, indicating that more than half of the city remains permeable.

[14] Reference: https://www.nearmap.com/products/imagery/

Map A2 1- Impervious area- NDVI and classification method



Title:

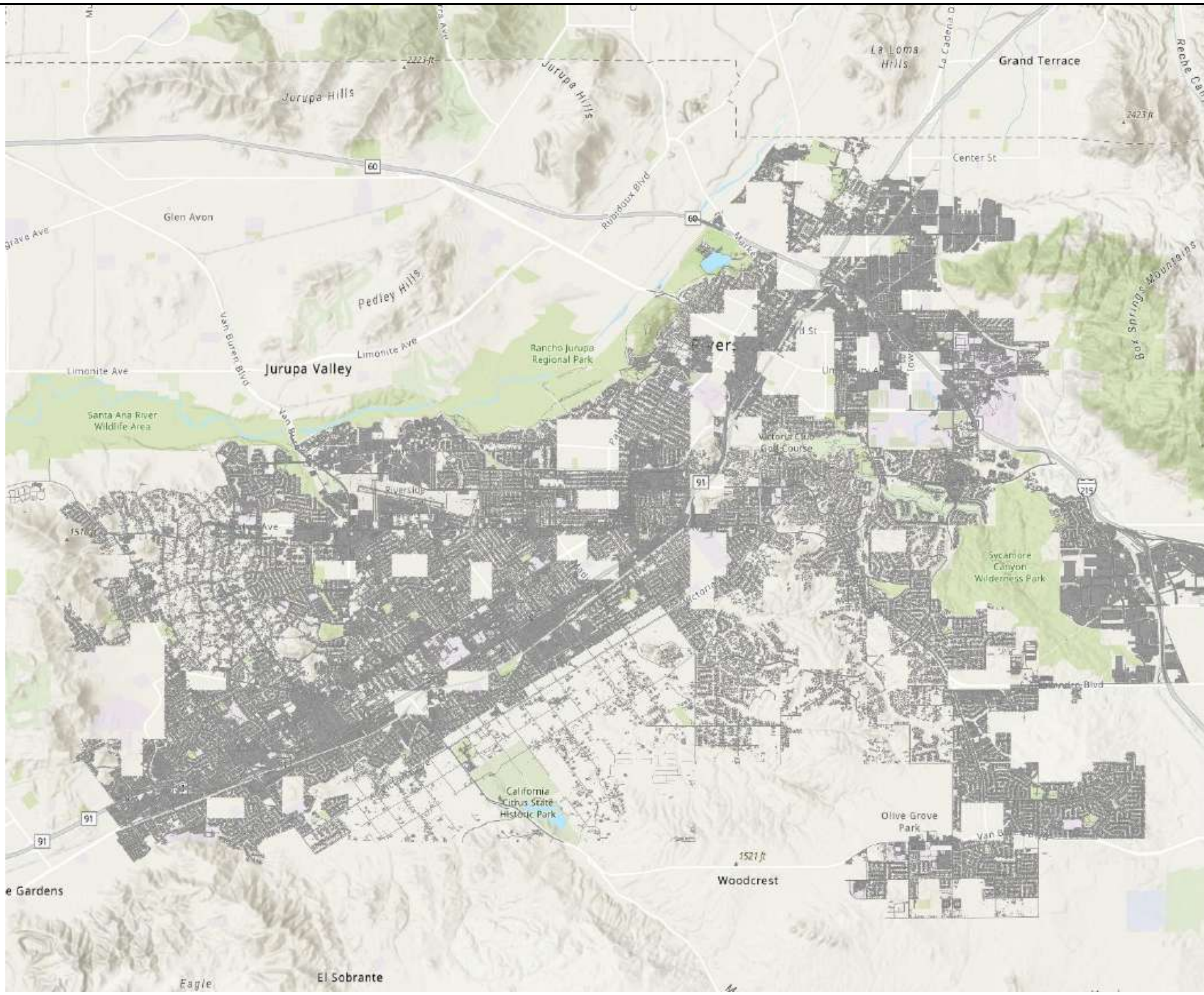
Impervious area- NDVI and classification method

Legend

Impervious area

SC: 1/80,000

Map A2 2- Impervious area- Nearmap's method



Title:

Impervious area- Nearmap's method

Legend

Impervious area

SC: 1/80,000

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